AD NUMBER
AD854328
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; NOV 1968. Other requests shall be referred to Air Force Armament Laboratory [ATCC], Egling AFB, FL 32542.
AUTHORITY
ADTC/OI, #1, 16 Mar 1978

AD854328

AFATL-TR-68-138

RETARDED EXERCISE MUNITION SYSTEM

S. Maruko
Nortronics, A Division of Northrop Corporation

TECHNICAL REPORT AFATL-TR-68-138

NOVEMBER 1968

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Armament Laboratory (ATCC), Eglin AFB, Florida 32542.

AIR FORCE ARMAMENT LABORATORY

AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE

EGLIN AIR FORCE BASE, FLORIDA

105

RETARDED EXERCISE MUNITION SYSTEM

S. Maruko

FOREWORD

This report covers a program performed by Nortronics, A Division of Northrop Corporation, 500 E. Orangethorpe Avenue, Anaheim, California, under Air Force Contract No. F08635-68-C-0003, "Retarded Exercise Munition System," Air Force Armament Laboratory, Eglin Air Force Base, Florida 32542. The Air Force Project Officers were Mr. L. G. Nelson (ATCC) and Lt. D. E. Metzgar (ATCC).

The contract period was from 1 August 1967 to 31 July 1968. The chief contributors to this program were A. A. Hodgson, program director, H. B. Stormfeltz, project manager, S. Maruko, project engineer, J. A. Kallas and W. F. Clemens. The contractor's report number NORT 68Y211.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

JOHN E. HICKS, Colonel, USAF
Chief, Bio-Chemical Division

ABSTRACT

This program was to design, develop and test an operational downward ejected airstrike munition and marking material. These munitions are nonhazardous substitutes for munitions used in combat to be employed in joint field training exercises to produce air strike realism and provide tangible evidence of the air strike effects for evaluation. The munition designed, developed and tested was a munition configuration based on a barrel stave type canister employing a simple retardation device to actuate munition separation and to decelerate a rigid component to a nonhazardous impact velocity. The inherent design features of the retarded exercise munition provides sufficient flexibility to utilize a variety of marking submunition configurations. It was concluded that the retarded exercise munition is simple, economical and requires further development to be an operationally feasible nonhazardous exercise munition which provides realism and improved scoring accuracy.

(The reverse of this page is blank)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Concluded)

LIST OF TABLES

SECTION I

INTRODUCTION

It is generally known that neither pilots nor ground troops are effectively motivated by air strikes in joint field exercises since the desired realism is not achieved. At present, strike aircraft make passes over troop targets without delivering any munitions. Damage estimates are made without tangible evidence and troops are removed from the exercise as air strike casualties based on the subjective evaluations of the umpire. The objective of this program described herein was to design, develop and test a downward ejected retarded exercise munition and marking material which would increase realism and provide an effective means to evaluate air strikes in joint field training exercise involving Army and Air Force personnel. The retarded exercise munition performance requirements and design parameters were primarily based on the study and recommendations made in technical report AFATL-TR-67-77, "Tactical Exercise Munitions." To systematically develop the exercise munition, the following basic requirements and parameters must be met:

(1) Nonhazardous and nondestructive to ground personnel and property.

(2) Deliverable from high performance tactical fighters using inventory dispensers.

(3) Provide a clear indication of the effects of air strikes visible to both umpires and troops to increase exercise realism and scoring accuracy.

(4) Produce effects (nonpermanent target marks) which are representative of combat air strikes.

The initial munition concept was based on a parachute retarded exercise munition system which disseminates marking material after deployment of the parachute. However, a study of a variety of munition concepts and the design evaluation of the more promising concepts including the parachute retarded munition established the barrel stave canister munition to be the best concept for further development.

The marker investigation was divided into two tasks - (1) the development of a washable marking fluid and optimizing its hue and (2) the analysis, fabrication, testing and selection of a marker (submunition) configuration to produce the desired dispersion and suitable mark size

A water soluble marker dye formulation was established and its hue was optimized between two "Day-Glo" fluorescent pigments - fire orange and saturn yellow. A modified flechette configuration was selected for the marker. The design of the retarded exercise munition was based on the barrel stave canister filled with the flechette type markers. This munition system was designed, developed, fabricated, and tested. Refinements were made based on the value engineering and development test program resulting with a series of changes until the final configuration was resolved.

SECTION II

PROJECT METHODOLOGY

The project methodology consisted of two sequential phases. Phase I included a progra study for the exercise munition systems for the SUU-13/A dispenser, feasibility tests of munition concepts, and selection of a munition concept for further development. Phase II involved the design, fabrication, development and testing of the selected munition concept.

The three primary study tasks in Phase I were:

(1) Marker investigation

(2) Munition concept and design analysis

(3) Preliminary design of an exercise munition for the TFDM dispenser.

The marker investigation was divided into development of a suitable marking material and evaluation of a number of marker configurations and the selection of a marking system for the exercise munition. The munition concept and design analysis required a detailed engineering study of a variety of munition concepts before selection of the most promising concept was made. The engineering study included:

(1) An aerodynamic analysis of the munition concept for safe separation of the ejected munition, munition ballistics after ejection until munition opening, and terminal effects of munition parts and submunitions

(2) A stress analysis of each munition concept to establish structural integrity of the munition under ejection, aerodynamic and hydrostatic forces induced upon the munition

(3) Safety analysis for functional reliability.

The retarded exercise munition concept selected for further development was the barrel stave munition concept and flechette type marker configuration. Preliminary design of the exercise munition for the TFDM was performed based on the information accumulated in the design evaluation of the exercise munition system for the SUU-13/A dispenser.

The objective of Phase II was to design and fabricate sufficient munitions for preliminary testing and development of the selected munition concept culminated by the actual aircraft ejection tests of the munitions. The engineering and design efforts involved:

(1) Stress analysis of the munition structure

(2) Design evaluation to simplify the munition design and fabrication costs

(3) Drawing preparation and fabrication of parts

(4) Development testing of the munition components and the complete munition assembly.

The test program was designed to resolve functional options and demonstrate the ability of the retarded exercise munition system to fulfill operational and safety requirements. The tests involved:

(1) Preliminary tests of the markers to evaluate marker structure, marker dye and mark size

(2) Static ejection tests of complete munitions to determine operational sequence of the munition

(3) Actual aircraft ejection tests.

Prior to the aircraft ejection tests, aerodynamic analysis was performed to establish munition dynamics, safe separation of the ejected munitions, and marker trajectory. Design modifications were made to the munition on the basis of the test results. A value engineering program was instituted near the beginning of Phase II and was maintained for the balance of the program.

SECTION III

MARKER STUDY

The marker study was performed to establish a marker configuration and marking material to satisfy the requirements specified for the Retarded Exercise Munition program. These requirements are:

(1) Be nonhazardous and nontoxic.

(2) Mark should be visible to both troops and umpires at a distance of 200 feet.

(3) Single minimum mark size should be 0.5 inch to 1 inch in diameter.

(4) Marking material hue should be visible under adverse lighting conditions against a tan or olive green background.

(5) Trajectory should be predictable.

MARKER INVESTIGATION

Marker investigation during Phase I consisted of three tasks which were:

(1) Optimize the formulation and hue of the marking material

(2) Evaluate a variety of marker configurations

(3) Select the marker configuration for Phase II development and finalize marking material formulation.

A detailed discussion is presented in appendix I.

Marking Material

The marking material formulation was finalized after performing a thorough investigation of suitable pigments and dyes and human engine ring studies to optimize the hue of the marking material. Of the numerous pigments and dyes the most promising was a daylight fluorescent pigment. This type of pigment is suitable for use in systems based on aqueous, aliphatic and most aromatic hydrocarbons. A water soluble resin was used to suspend the fluorescent pigment. The hue was optimized by performing human engineering studies using five colors of the visible spectrum ranging from 545 to 610 millimicrons against white, beige, and olive green backgrounds. The preferred colors were fire orange and yellow. Of the two colors observers showed a preference for yellow.

The formulation of the mixture was finalized and a sample was submitted for toxicological and dermatological testing.

Marker Configuration

The flechette marker was selected after design, aerodynamic analysis, fabrication, and tests were performed on a variety of marker configurations. The markers were divided into two categories, wet and dry, to distinguish the marking material. The wet types included basic shapes, encapsulated porous material, modified flechettes, vaned cylinders, and maple seed carriers. The dry carriers include open-cell foam plastic impregnated with dry pigments, encapsulated powders, and pelletized powder pigments.

Drop tests of each marker configuration were performed from a 120-foot drop tower. Test results revealed that dry marker had poor marking ability and poor dispersion. The performance of the wet markers was dependent upon configuration.

The marker configuration selection for Phase II development was made by a comparative evaluation of the merits of each configuration relative to all of the marker types investigated. As a result, the flechette marker was selected for further development.

MARKER DEVELOPMENT

The marker development during Phase II was directed towards designing a flechette marker that satisfies all marking and nonhazardous requirements specified, is economical to fabricate in the small quantities required for this program, and also is readily adaptable for mass production.

A cost survey of manufacturing techniques such as injection molding, blow molding and vacuum forming, and the related cost made it apparent that the tooling cost alone was prohibitive for fabrication of small quantities of the flechette markers. As an alternative, the flechette marker was designed to utilize a heat shrinkable plastic tube, heat-shrunk to the desired shape over a mandrel. The tooling cost was negligible and the heat shrinkable plastic tubing was readily available. To simplify fabrication of the flechette body a tail cone was incorporated in place of the fins. Flechette stability with the cone was about the same as with fins.

An investigation of gelatin capsules, high temperature wax and film plastic materials and forming and sealing techniques to encapsulate the marking material indicated that a frangible material produces the best results. Marking material encapsulated in film plastic produced negligible mark size because of the film plastic stretching and yielding on impact rather than rupturing. The best mark size was produced by marking material encapsulated in high temperature wax which shattered readily at impact. However, a carefully controlled process is required to form the wax nose capsule. The design and development of tooling for fabrication of wax capsules was considered to be impractical for small quantities. The tests with the wax nose caps established the following requirements for a frangible nose cap:

(1) It must withstand aerodynamic forces at 550 knots.

(2) It must shatter on impact.

(3) It must be economical, easy to fabricate, or readily available.

Preliminary tests with gelatin capsules produced mark sizes that were 1 1/2 to 2 1/2 inches in diameter. The capsule is rigid and brittle, easy to handle, readily available, and economical both in small and large quantities. A negative aspect of the gelatin capsule was the fact that it became soft and jelly-like within four to five days after filling with the marking material. To expedite munition and marker development, the gelatin capsule was utilized to prove flechette marker design feasibility. At the same time a search for a suitable replacement was initiated. The final flechette marker configuration is based on incorporating a brittle epoxy base plastic capsule similar in size and shape as the gelatin capsule.

A survey of manufacturers of small plastic bottles, ampules and capsules revealed that plastic capsules can be molded to any desired size and shape. However, the permeability of most plastic material would enable an aqueous marking material to dissipate over a 5-year storage period. Plastic material, such as PVC has good fluid retention qualities but is so tough that it will not shatter on impact. None of the manufacturers had any experience with frangible epoxy base plastic material.

Pilot quantities of capsules were formed using epoxy base material. These capsules exhibited the desirable quality of having structural rigidity and fragility to shatter on impact. Sufficient data was not accumulated at the end of the program to project any cost estimates for manufacturing epoxy capsules.

It was noted during the aircraft ejection tests of the retarded exercise munition that a cloud consisting of markers, marker dye, and small foam plastic balls would spray forth at munition opening. Examination of the markers recovered near the release point indicated that the nose of the capsules were breaking off at munition opening. To avoid capsule breakage due to the impinging aerodynamic force, the capsules should be designed with the wall thickness tapering from maximum thickness at the nose to minimum thickness at the base as shown in figure 1. The stress raiser should be incorporated to assure frangibility of the capsule at impact.

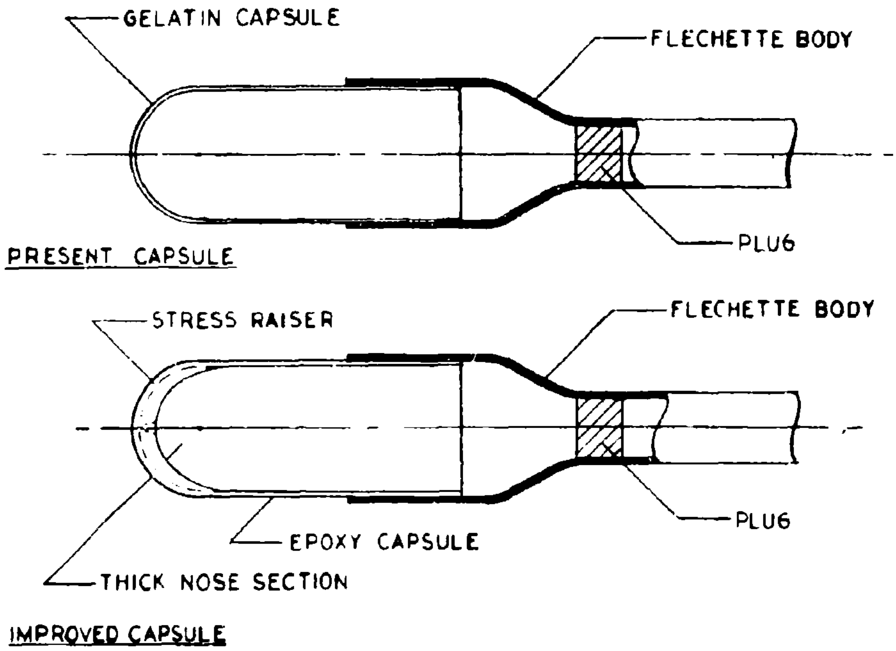


Figure 1. Improved Capsule Design

SECTION IV

MUNITION DESIGN

The primary requirement in the design and development of the Retarded Exercise Munition System was to ensure its entire function to be nonhazardous, 100 percent fail safe, and to present no risk of injury to ground personnel or damage to ground equipment or the delivery aircraft.

CONCEPT EVALUATION AND SELECTION

In addition to the parachute retarded exercise munition concept, munitions concepts incorporating several types of retardation devices were investigated. The three prime candidates of this investigation for further design and development were:

(1) The parachute retarded concept

(2) The autorotating vane concept

(3) The barrel stave concept.

Design evaluation of the three candidate concepts resulted with the barrel stave canister being recommended for further development.

PHASE I DESIGN ANALYSIS

The design of Retarded Exercise Munition System evolved from the basic barrel stave concept model to the final feasibility munition configuration through a series of changes based on stress analysis, design analysis, value engineering and test results. The initial concept (figure 2) was designed to contain markers in a solution of marking material. The sequence of operation after munition ejection consisted of the deployment of the drag device which extracted the top plate from the container to initiate munition opening and marker dispersion.

Stress Analysis

A stress analysis of the induced loads on the barrel stave canister (refer to appendix III) and its effects on the load bearing members revealed:

(1) Excessively high loads were induced on the staves at peak ejection pressure.

(2) Extremely high stresses were induced by the hydrostatic pressure, if the markers were suspended in a fluid.

(3) Aerodynamic loads on the munition structure were not as serious as the hydrostatic effects.

The munition design was modified to incorporate an interconnected compressive column through the center of the canister to absorb the compressive loads at ejection. Thin plastic disks were embodied as integral members of the

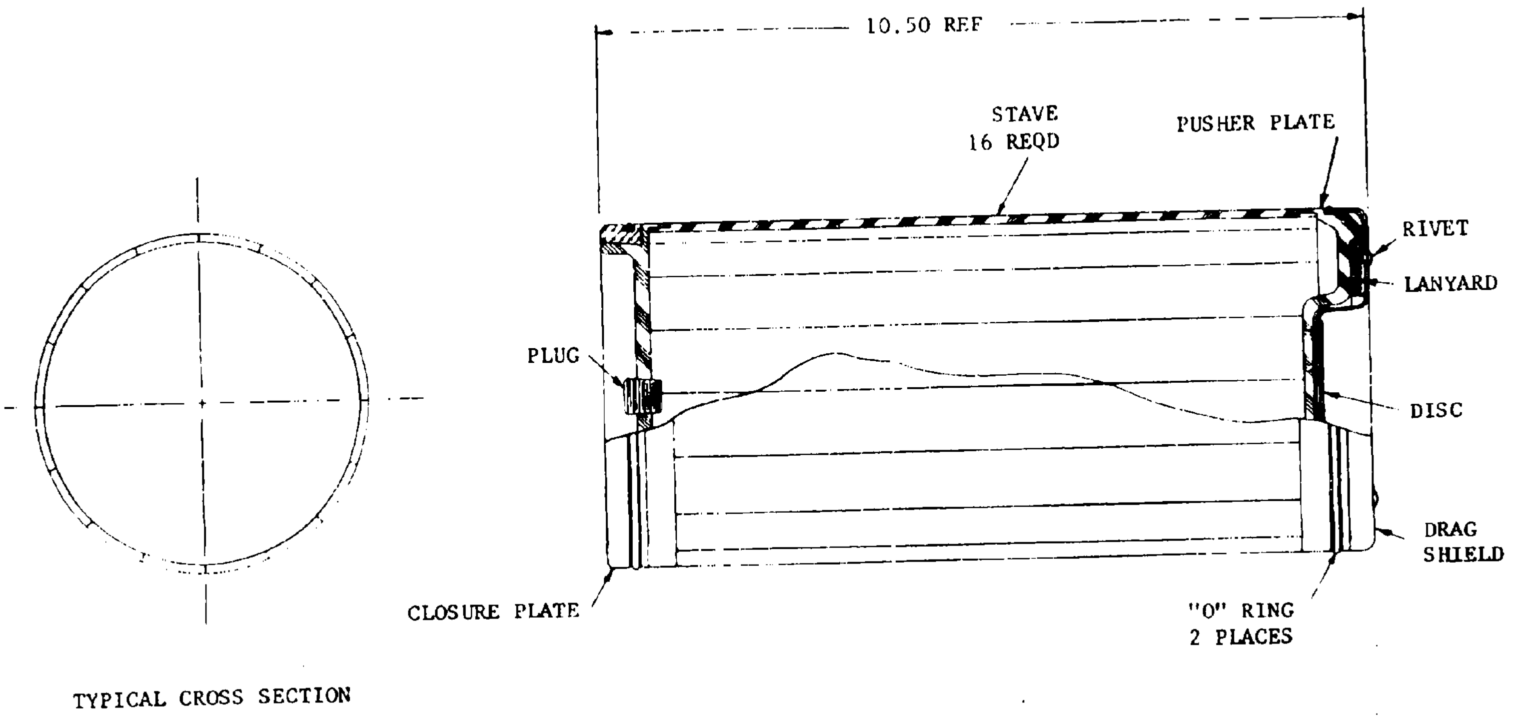


Figure 2. Barrel Stave Concept

interconnected compressive column to reduce the cumulative effect of the hydrostatic pressure. The disks also provide internal support to the staves to absorb the aerodynamic forces impinging on the canister.

The problem concerning the hydrostatic pressure was eliminated by incorporating flechette markers which encapsulated the marking material and by using small styrofoam plastic balls as packing material around the flechette markers to absorb the setback force at munition ejection.

Other methods to absorb the induced stresses were:

(1) The use of a thin metal strap wrapped around the middle of the barrel stave canister held together by a wind tab or by a piano-type hinge held together by a release pin.

(2) Interlocking the staves and incorporating stiffeners in the staves.

The potential hazard of thin metal straps impacting ground personnel at high velocity preclude their use. The possibility of the stiffeners affecting the aerodynamics of the staves and degrading its Magnus lift values negate the use of the interlocking staves.

Minimum Payload

The results of a study to establish the minimum number of markers per canister as well as the number of markers required for marking higher percentages of randomly distributed troops in a 1500-square-foot area are shown in table I. This table is applicable for munitions ejected at 100 and 500 feet at 165 KIAS and 500 feet at 550 KIAS.

The size of the flechette markers can be adjusted to increase the number of markers per canister; however, the practical limit was established at 540.

TABLE I. NUMBER OF MARKERS REQUIRED TO MARK A GIVEN PERCENTAGE RANDOMLY DISTRIBUTED TROOPS

Number of Markers	Fraction Marked
360	0.30
720	0.51
1080	0.66

Troop Safety

A stringent limitation was imposed on the mass and terminal velocity of markers and munition canister components impacting the ground. Study of Ballistic Research Laboratories Report No. 1269, Criteria for Incapacitating Soldiers with Fragments and Flechettes by Kokinakis and Sperrazza, indicates that an energy level of 10-foot-pounds per square inch constitute a hazard to the body as a whole and an even greater hazard to the head and neck area.

Accordingly, to reduce the probability of injury of ground personnel by the marker or munition canister, components design changes were made to reduce the maximum impact energy per unit area to 8 foot-pounds per square inch.

TFDM Dispenser Study

A "paper study" for a retarded exercise munition for the TFDM dispenser was conducted during Phase I. Discussion and sketches are presented in appendix IV.

PHASE II DESIGN DEVELOPMENT

Munition Design

A design review in conjunction with the value engineering program eliminated a number of small intricate parts used to interlock the two end plates and simplified the overall munition design. Static ejection tests and compression tests revealed that the staves were buckling under the ejection force, resulting with the premature separation of the munition. Design modifications were made to incorporate a sliding sleeve over the staves as a means to prevent the staves from buckling. The sleeve was bonded to the pusher plate. The munition configuration used in the first aircraft ejection test is shown in figures 3 and 4.

The housing for the pyrotechnic secondary release system is bonded to the pusher plate in the center. To enclose the secondary release system, the uppermost compressive cylinder has a larger diameter than the other compressive cylinder. The compressive cylinders form a compression column to direct the downward ejection force through the center of the canister into the closure plate. A disk is bonded to each of the compressive cylinders to separate each row of markers. The bottom compressive cylinder is bonded to the closure plate. The staves are held in position by the pusher plate and closure plate.

Sequence of Operation

Munition sequence of operation upon ejection from the SUU-13/A dispenser consists of:

(1) The sleeves prevent the staves from buckling due to the ejection force and impinging airstream.

(2) The drag plate is deployed as the munition clears the dispenser and is fully deployed after a 0.2-second delay.

(3) Snatch force pulls the pusher plate assembly from the canister to initiate complete separation of the canister and marker dispersion.

Design Improvement

The aircraft ejection tests to demonstrate design and operational feasibility of the munition under actual flight conditions resulted with the munitions functioning at 165 and 250 KIAS but malfunctioning at 350 and 550 KIAS. Components such as the base plate, the compression column with its separator

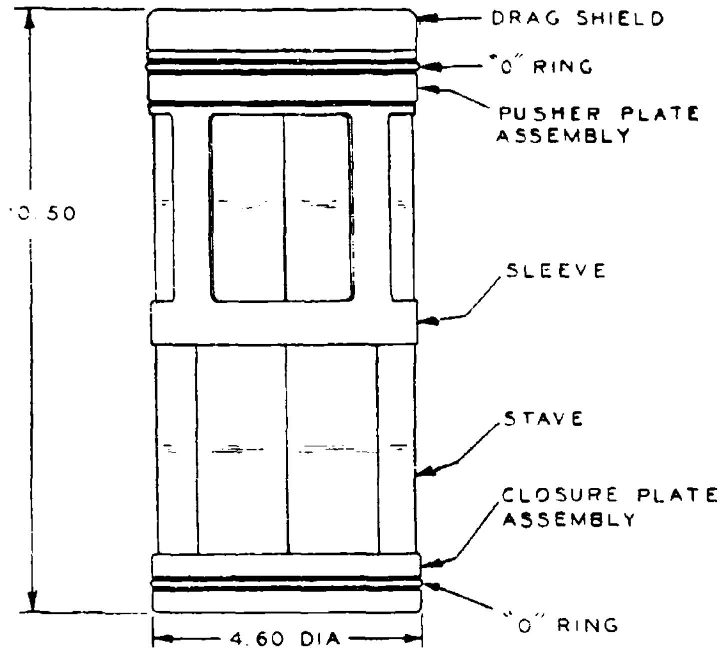


Figure 3. External Configuration of the Barrel Stave Canister

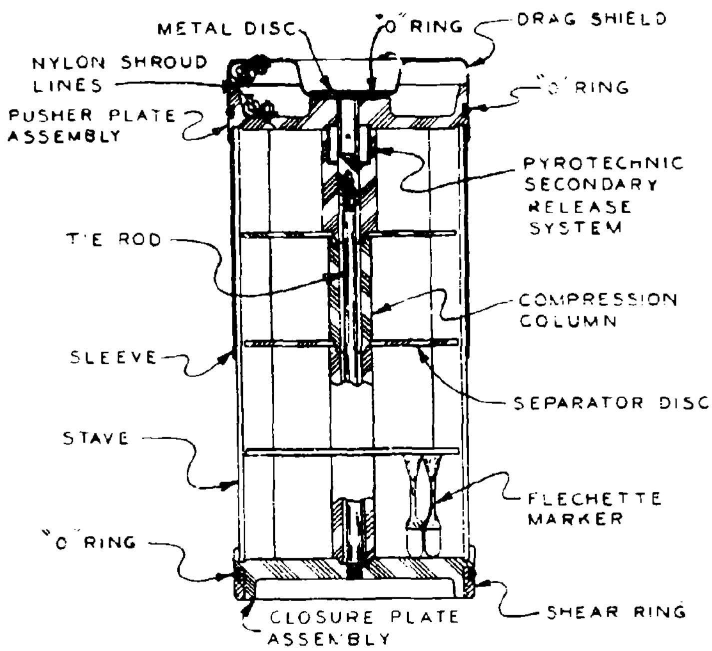


Figure 4. Cross Section of the Barrel Stave Canister

disk, and the pusher plate with the aluminum sleeve impacted the ground with potentially hazardous energies. To satisfy the requirements for a nonhazardous munition, the following design changes were incorporated for a second aircraft ejection test (figure 5):

(1) A rubber closure plate with a light plastic honeycomb stiffener was incorporated to replace the plastic and aluminum closure plate.

(2) The sliding sleeve over the staves was replaced by a two-piece nylon shroud interconnected by two tear strips attached to the pusher plate assembly.

(3) The interconnected compression column and the separator discs were replaced with thin, plastic cup-shaped marker containers.

(4) The fiberglass drag plate was reinforced to withstand the high aerodynamic forces at 550 KIAS.

A sketch of the redesigned munition is shown in figure 5.

The redundant release system was eliminated in the redesigned munition on the basis of the reliability analysis, appendix V, which indicated greater reliability can be achieved by improving the aerodynamic mode for munition opening.

The sequence of operation of the munition remains the same except the fabric shroud, replacing the aluminum shield, can be ripped off by the aerodynamic force or pulled off by the drag device. Marker dispersal from the marker cup is accomplished by an extractor disc which pulls the markers out of the marker cup. A braided nylon line interconnects the extractor plate with the drag disc which provides the pulling force to extract the flechette markers.

The second aircraft ejection test of the improved retarded exercise munition resulted with complete munition opening and separation at 350 and 550 KIAS aircraft velocities and partial separation at 165 KIAS aircraft velocity. The markers in the marker cups were not fully dispersed at 350 and 550 KIAS because of the nylon line interconnecting the drag plate and the marker extractor plate was snapping due to the aerodynamic force at those velocities Better marker dispersion resulted at 165 KIAS aircraft velocity from marker cups separating from the munition and when the interconnecting line did not snap. Each marker cup produced its own elliptic pattern which resulted with a ground pattern consisting of clusters of marker impacts.

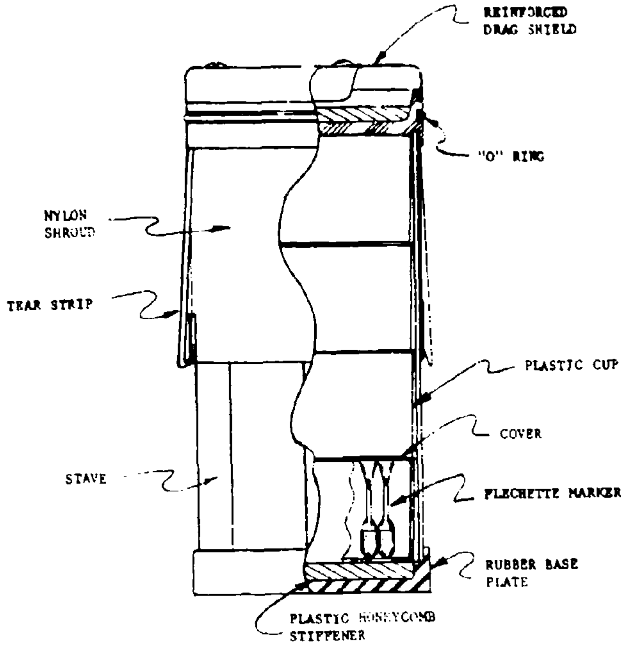


Figure 5. Barrel Stave Canister Rems II

SECTION V

DEVELOPMENT TEST PROGRAM

The development test program was designed to cover a broad spectrum of test activities to support engineering, design and development efforts. Tests during Phase I were conducted to make comparative evaluations of marker configurations and munition concepts as a selection criterion for the Phase II development of a marker and munition canister. The test program during Phase II was performed to support marker and munition canister development, preliminary tests of the munition system, and aircraft ejection tests of the munitions system.

PHASE I - EVALUATION TEST

The development test program during Phase I was coordinated with the marker investigation and munition concept and design evaluation tasks. The tests performed for the marker investigation were primarily drop tests of a variety of marker configurations such as basic shapes, flechette, vaned cylinder, maple seed, impregnated foam, encapsulated powder and dry pellets, from heights of 60 and 120 feet to establish marker dispersion and mark size. The results of the tests performed from a 120-foot drop tower are shown in table II. Impact velocity of the markers was not determined because an unfavorable wind condition blew the markers away from the target area where high-speed cameras were located.

Feasibility test models of the three munition concepts - parachute retarded, autorotating vane, and barrel stave - were tested from a 120-foot drop tower. Two series of tests were performed. The results of the tests are shown in table III. Munition separation began 30 to 40 feet from ejection and impact velocity was approximately 45 fps for both the parachute retarded canister and staves. The ejection velocity was approximately 120 fps.

PHASE II - DEVELOPMENT TEST

Phase II tests were performed to resolve functional options and demonstrate the capability of the Retarded Exercise Munition System to fulfill operational and safety requirements. The type and order of tests are listed below:

(1) Preliminary Tests

Marker - Static and Dynamic
Canister - Static Compression

(2) Munition Ejection Tests

Drop Tower
Ground Level

(3) Aircraft Ejection Tests - Munition Ejection Tests from Aircraft

TABLE II. MARKER EVALUATION DROP TEST

Marker Type	Marking Ability	Dispersion	Flight Path	Impact Velocity
Wet - Basic Shape				
Flocked Wood	Poor	Good	Glided	Low
Saturated Foam	Good	Poor 10-foot diameter	Dropped Vertically	Medium
Encapsulated Foam	Satisfactory	Good	Glided	Low
Modified Flechette	Excellent	Satisfactory 20-foot diameter	Vertical Down	High
Vaned Cylinder	Fair	Poor 10-foot diameter	Spiraled Down	Medium
Maple Seed	Satisfactory	Good 50-foot diameter	Spiral Glide	Low
Dry -				
Impregnated Foam	Poor	Good 30-foot diameter	Glide	Low
Encapsulated Powders	Poor	Fair 20-foot diameter	Vertical Down	Low
Pellets	Poor	Fair 20-foot diameter	Glide	High

TABLE III. CONCEPT FEASIBILITY TEST

Munition Concept	Distance to Munition Separation (feet)	Distance to Impact (feet)	Dispersion	Remarks
Test Series No. 1				
Parachute	30	200	Negligible. bulk of markers remained in container.	Upper plate of marker broke. Parachute impacted near tower base.
Rotating Vanes	30	100 300	Negligible, markers tended to stick together.	Upper vanes rotated immediately. Lower vanes did not rotate.
Barrel Staves	Failed to Open	310	None.	Drag plate cocked over and did not pull end plate off to initiate separation.
<u>Test Series No. 2</u>				
Parachute	40	100	None.	Outer container failed near top and prevented dissemination of markers. Parts made from cast Acrylic plastic. Model was made for static tests not for ejection tests.
Rotating Vanes	50	200 300	None. No markers used.	Upper vanes rotated immediately after separation. Lower vanes traveled additional 100 feet before rotating.
Barrel Staves	40	100 200	None. No markers used.	Staves autorotated earthward and scattered over an area 100 feet in diameter. Small parachute used to pull top plate off. Parachute did not open but end plate still came off.

Marker Tests

Initial marker tests were performed to compare the free-fall characteristics of flechette markers and mark size produced by markers using a film plastic nose cap and those using a wax-dipped nose cap. The three types of markers tested are shown in figure 6. The markers were dropped from a height of 60 feet in random orientation onto a concrete surface below.

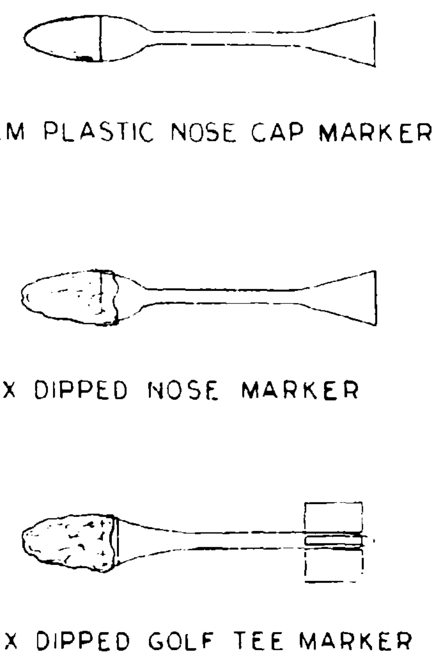


Figure 6. Flechette Markers Used in the 60-Foot Drop Test

The flechettes with the waxed-dipped nose produced the best mark sizes which were approximately 1 1/4 to 1 1/2 inches in diameter. The film plastic nose cap did not burst open on impact. The results of this test indicated that markers using a frangible nose cap produce larger mark size than those using a film plastic nose cap. Because of the difficulty in making flechettes with wax dipped nose, flechettes with gelatin capsules filled with marking material were drop tested, to evaluate the resulting mark size produced. Mark size was about 2 to 2 1/2 inches in diameter.

Laboratory tests were performed to establish compatibility between the gelatin capsule and the marker dye solution. The filled capsules were examined at arbitrarily selected time intervals of 48 and 96 hours and 7 days. Degradation of the filled capsule was not discernible after 48 hours. After 96 hours the capsules exposed to the atmosphere exhibited some softening whereas those in a sealed container remained unchanged. The capsules in the sealed containers showed initial signs of softening after 7 days and the capsules exposed to the atmosphere were soft and had a jelly-like consistency. Also, a noticeable amount of dye solution leaked out of the capsule as it softened.

After the first 72 hours, some of the capsules used for the compatibility test were assembled with the flechette body (figure 7) and dropped from a height of 60 feet onto a concrete surface. The capsules shattered on impact and consistently produced a mark size approximately 2 by 2 1/2 inches in size The capsules containing foam plastic and marker dye solution produced a comparatively smaller mark size. The impact velocity was estimated to be 56 fps. Two flechette markers were dropped on a grassy surface and the resulting mark size was only five-eighths of an inch in diameter for one marker and negligible for the other.

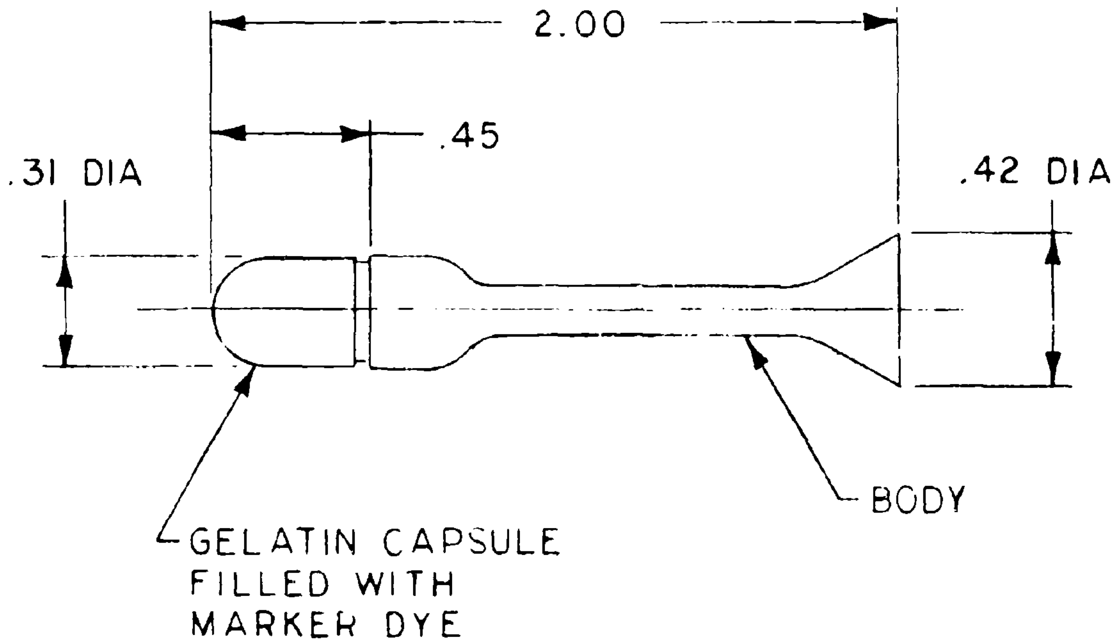


Figure 7. Flechette Marker

The first series of marker impact was performed with flechette markers using gelatin capsules to establish the relationship between:

(1) Air gun regulator pressure and muzzle velocity.

(2) Impact velocity and mark size on rigid foam plastic blocks, Celotex boards and appropriate clothing.

(3) Impact velocity and marker indentation into rigid foam plastic blocks.

(4) Impact velocity and marker indentation into Celotex boards.

Item (2) above established the impact velocity at which the marker would become hazardous. The data obtained for items (3) and (4) were used for the aircraft ejection test. The rigid foam plastic blocks and Celotex boards

were used as targets and velocity indicators, and the test data correlated with the marker indentation in the target material during the aircraft ejection tests, established the marker impact velocity. The flechette markers were shot out of an air gun against a target 25 feet away.

Preliminary tests to check out the test setup revealed that capsules with foam plastic inserts degraded the mark size. Therefore, capsules with foam plastic inserts were not used for the remainder of the program.

The test sequence consisted of markers being shot at the following items:

(1) Rigid polystyrene foam plastic blocks.

(2) GI utility jacket draped over the foam plastic block.

(3) Celotex board.

(4) GI utility jacket draped over the Celotex board.

In addition, markers with scored capsules were shot at the GI jacket to determine if mark size would be increased by putting stress raisers in the capsules. Markers also were launched vertically into the air to evaluate terminal effects.

Test results (table IV) revealed that the mark size produced by the markers was proportional to the hardness of the impacted surface. The markers penetrated into the foam plastic blocks leaving a small mark size. Markers impacting the Celotex board produced mark sizes 2 by 3 inches or larger. Mark size on the field jacket varied from 1/4-to 1/2-inch diameter marks in the loosely draped areas to 1 1/2- to 2 1/2-inch diameter splotches in the stretched area. (Markers with scored capsules produced larger mark size than unscored capsules.) The mark size produced by markers launcher vertically to impact at terminal velocity produced 1/8- to 3/8-inch diameter mark sizes on sandy surfaces and 1- to 1 1/2-inch diameter mark sizes on asphalt surfaces.

The second series of tests were performed to establish:

(1) The relationship between impact velocity and flechette marker indentation into extruded polystyrene foam blocks.

(2) The relationship of impact velocity to a mark size on a GI utility jacket draped over a piece of meat.

(3) The relationship of marker dye viscosity to mark size.

The first set of marker tests were made to establish the relationship between impact velocity and marker penetration into rigid polystyrene foam blocks.

The second set of marker tests were made to evaluate the mark size produced by markers impacting a GI utility jacket, draped over a piece of meat, at various impact velocities and with various marker dye viscosities.

TABLE IV. FLECHETTE MARKER IMPACT TEST SERIES NO. 1

Test	Regulator Pressure (psi)	Muzzle Velocity (fps)	Impact Velocity (fps)	Target Material	Target Penetration (inches)	Mark Size (inches)	Remarks
1	50	214	---	Rigid Foam Plastic	.30	0.4 x 0.5	Markers penetrated into foam plastic instead of spattering
2	75	177	172		.25	0.4 x 0.4	
3	100	220	199		.25	1.5 x 0.4	
4	125	133	130		.18	0.5 x 0.45	
5	150	169	---	Rigid Foam Plastic	.25	0.45 x 0.4	
6	200	181	168		.35	0.5 x 0.4	
7	100	126	118	Field Jacket Over Rigid Foam Plastic	---	0.5 x 0.25	Small mark size produced in loosely draped area. Large mark size produced in stretched out area.
8	125	184	148		---	0.62 x 0.62	
9	125	143	120		---	0.5 x 0.25	
10	150	202	166		---	1.0 x 4.25	
11	50	---	165	Celotex Sheet	Negligible	8 x 5	Marker splatters extremely well against harder surface.
12	75	---	177		Negligible	4 x 3	
13	100	---	156		Negligible	6 x 4	
14	125	---	203	Celotex Sheet	Negligible	2 x 3	
15	150	---	168		Negligible	3 x 4	
16	100	---	164	Field Jacket Over Celotex Sheet	---	4 x 3	Used serrated capsule. Impacted loosely draped area.
17	100	---	---		---	0.75 x 0.4	
18	50	---	---		---	2.5 x 1	

The test results shown in table V indicate the marker impact velocity in most cases to be higher than the theoretical terminal velocity of the marker. The best mark size was produced by markers filled with low viscosity dye. High-speed movies revealed the low viscosity dye to splatter best and cling to the impacted jacket. The higher viscosity dye did not splatter and stick to the jacket, but tended to bounce off the jacket resulting with a smaller mark size.

Canister Test

A compression test was performed on the barrel stave canister assembly to establish the critical load at which the staves begin to buckle. An empty canister assembly was used as the test specimen. The first compression test indicated that the staves begin to deflect as the load approached 600 pounds.

In the second test, a strip of masking tape one-half of an inch wide was wrapped around the middle of the canister. The tape was applied to restrict the deflection of the staves in order to increase the critical load. Initial indications of stave deflection were recorded at 1250 pounds and stave deflection was visibly noticeable at a maximum load of 1500 pounds.

The results indicated the load carrying capacity of the barrel stave canister can be doubled by incorporating a strap around the middle of the canister.

Drop Tower Test

Munition ejection tests from the 120-foot drop tower were performed to evaluate:

(1) Munition

(2) Munition structure

(3) Marker trajectory

(4) Marker dispersion

(5) Marker impact velocity

(6) Drag plate and parachute drag devices.

The test results indicated the munition did not function as expected, marker dispersion was greater than computed, impact velocity was not determined, and both drag devices worked equally well. The staves peeled off prematurely, initiating canister separation.

Marker trajectory varied considerably from the computed trajectory. The disparity of the actual marker trajectory with the computed trajectory was due to premature separation of the canister, racking of the separator disk and damage to the marker capsule. Markers with the capsules intact impacted as far as 247 feet from the tower; markers with broken capsules impacted 40 feet from the base of the tower. The greatest concentration of markers

TABLE V. FLECHETTE MARKER IMPACT TEST SERIES NO. 2

Test	Regulator Pressure (psi)	Target Material	Marker Viscosity (Centipoise)	Impact Velocity (fps)	Penetration (inches)	Remarks
1	50	Rigid Foam Block	290,000	-	0.75	
2	75		290,000	145.0	1.00	
3	125		290,000	46.1	-	Bounced off target
4	100		290,000	157.5	1.50	Impact attitude 4 deg.
5	125		290,000	173.0	1.125	Capsule broke, impact attitude 10 deg.
6	25	Jacket over Meat	290,000	127.5	None for balance of test	Mark size 1 x .5 inches
7	50		290,000	135.0		Small mark size, bounced off target
8	75		290,000	161.0		Mark size 1 x 1.25 inches
9	100		290,000	160.0		Splattered, mark size 1 x .75 inches
10	125		290,000	216.0		Splattered, mark size 1.25 x 1.75 inches
11	50		480,000	151.0		Impacted sideways, no mark
12	25		480,000	130.0		Small mark, dye bounced off
13	75		480,000	159.0		No mark, dye splattered and bounced off
14	100		480,000	173.0		
15	25		60,000	78.8		No mark, capsule did not break
16	50		60,000	153.0		Mark size 2.25 x 1.5 inches
17	75		60,000	178.0		Mark size 1.5 x 1.5 inches
18	100		60,000	197.0		Mark size 2.0 inch dia.
19	125		60,000	217.0		Donut shape mark, 1.5 x .75 inches
20	50		1,050	148.0		Mark size 2.5 x 1.25 inches
21	25			167.0		Mark size 2.0 x 1.0 inches
22	75			167.0		Mark size 2.0 x 1.5 inches
23	100			200.0		Mark size 1.0 x 1.5 inches, hot tape
24	125			-		Mark size 2.0 x 1.25 inches

was located 78 feet from the tower. Marker dispersion covered a tear-drop shaped area 207 feet long and 33 feet wide (figure 8). The majority of the markers impacting 70 to 90 feet from the tower had broken capsules.

In the second test the wind was blowing at an angle towards the drop tower which blew the markers to one side and slightly behind the drop tower. Marker dispersion covered a tear-drop shaped area 234 feet long and 34 feet wide. Two areas of marker concentration were located approximately 50 feet apart (figure 8).

The rates of descent of the parachute retarded and drag plate retarded pusher plate were almost equal. The autorotating staves descended at a slower rate than the parachute or drag plate retarded pusher plate.

Munition Ejection Tests

Munition ejection tests were performed at ground level prior to the aircraft ejection test to establish:

(1) Effects of the setback force on the marker capsules

(2) Munition ejection velocity

(3) Munition function.

The munitions were fired at an angle 40 degrees above horizontal. The munitions used in the tests incorporated the latest design changes.

The results of the first series of tests performed prior to the first aircraft ejection test are shown in table VI. Design changes were incorporated based on the information acquired from the munition ejection test in preparation for the aircraft ejection test.

A second series of ground level munition ejection tests were performed to evaluate design modifications incorporated based on the test results obtained from the first aircraft ejection test. The design modifications were made primarily to satisfy the nonhazardous requirements and to improve munition performance.

The objective of the second series of munition ejection tests was to evaluate:

(1) The reinforced drag plate

(2) Rubber closure plate

(3) Fabric shrouds with tear strips used in place of the aluminum sleeve

(4) Marker cups

(5) Overall munition performance.

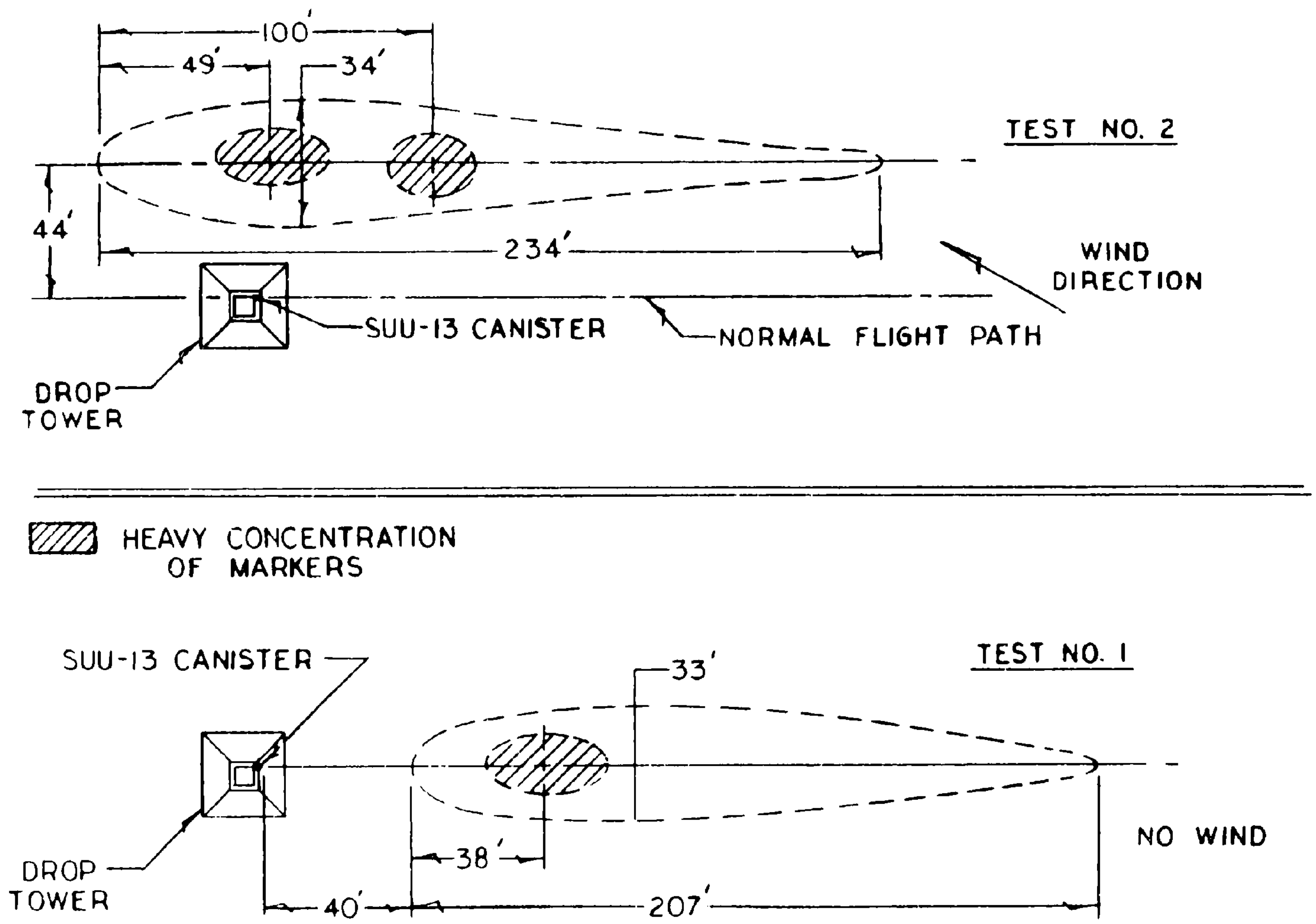


Figure 8. Marker Impact Area

TABLE VI. FIRST MUNITION EJECTION TESTS

Test	Ejection Velocity (fps)	Drag Device	Munition Operation	Remarks
1	183	Drag Plate	Partial Separation	Drag device was fully deployed but the sleeve did not slide off to allow complete munition separation. Markers in first two rows were damaged. Markers in foam plastic filler were not damaged.
2	190	Parachute	Partial Separation	Results were similar to test #1 above. The closure plate came off due to the parachute snatch force and portion of the first row of markers was disseminated.
3	111	None	None	Dummy payload was used to check ejection velocity using an ARD 863-4 pressure cartridge.
4	113	Drag Plate	Drag plate fully deployed canister failed to open.	Munition fully loaded with markers and small polystyrene pellets to simulate munition for aircraft ejection test. Slight damage to markers. Interference between sleeve and stave prevents munition separation.
5	112	Drag Plate	Satisfactory	Inside diameter of sleeve was increased. Fully deployed drag plate pulled off sleeve. Markers were dispersed as canister came apart.

The same test setup was used as in the previous series of munition ejection tests. The results are shown in table VII.

Upon completion of the munition ejection tests it was decided to incorporate the following:

(1) The drag disk with the extractor disk as the method to disseminate the markers

(2) A shear ring in the rubber closure plate

(3) A tight fit between the stave and rubber closure plate

(4) Nylon pins to lock the staves to the closure plate to prevent the closure plate from peeling off when ejected at high aircraft velocity.

TABLE VII. SECOND MUNITION EJECTION TEST

Test	Munition Weight (pounds)	Ejection Velocity (fps)	Munition Operation	Remarks
1	4.25	112	None	Dummy payload to establish ejection velocity
2	2.94	112	Complete Separation	Munition functioned as expected. Complete separation occurred 40 to 50 feet after ejection. Closure plate and simulated marker continued its trajectory to ground impact. Fabric shroud pulled off by fully deployed drag plate.
3	2.86	163	Complete Separation	Higher velocity due to ARD 863-1 pressure cartridge. High velocity required to actuate tear strip. Munition separation occurred 50 feet after ejection. Closure plate and simulated markers maintained trajectory to ground impact. Fabric shroud pulled off by fully deployed drag plate.
4	3.36	112	Complete Separation of munition seemed to occur prematurely	Munition separation occurred 25 to 30 feet after ejection. Munition appeared to separate prematurely. Closure plate appeared to pop off canister shortly after ejection. Partially sheared shear pin pulled tear strip off as munition was ejected from canister. Portion of flechette markers dispersed.
5	3.17	113	Complete Separation	Munition separated 40 to 50 feet after ejection. Closure plate appeared to peel off too soon. Fabric shroud pulled off by fully deployed drag plate. Drag disk interconnected to marker extractor disk in marker filled cup dispersed markers as expected. Drag disk with lanyard attached to bottom of marker cup to spill markers did not function as expected.

SECTION VI

AIRCRAFT EJECTION TESTS

The aircraft ejection tests of the retarded exercise munition were conducted in accordance to the delivery modes and conditions specified to demonstrate that munition performance would fulfill operational and safety requirements. The tests were performed with an F-86 jet aircraft with the retarded exercise munitions being ejected from a SUU-13/A dispenser.

The overall target size was 150 feet by 600 feet; 2- by 24- by 24-inch rigid foam plastic blocks were distributed to form a target grid as shown in figure 9. In addition, 4- by 8-foot Celotex boards were placed near the center of the target area. The release points, marker trajectory, and dispersion were established by a computer program.

In the first series of aircraft ejection tests, the first and second passes were made at 165 KTAS at aircraft altitudes of 500 and 100 feet respectively. The third pass was made at 550 KTAS from an altitude of 500 feet. The aircraft velocity was reduced to 350 and 250 KIAS after the third pass because the screw attachment points for the shroud lines were being torn from the fiberglass drag shield at the higher aircraft velocities. The results of the aircraft ejection test are summarized in table VIII. A discussion of the preparation for the aircraft ejection test is presented in appendix VI.

In the second series of aircraft ejection tests, the target setup was the same as the first series with the exception that the number of Celotex boards near the center of the target area was doubled. The results of the aircraft ejection test is summarized in table IX.

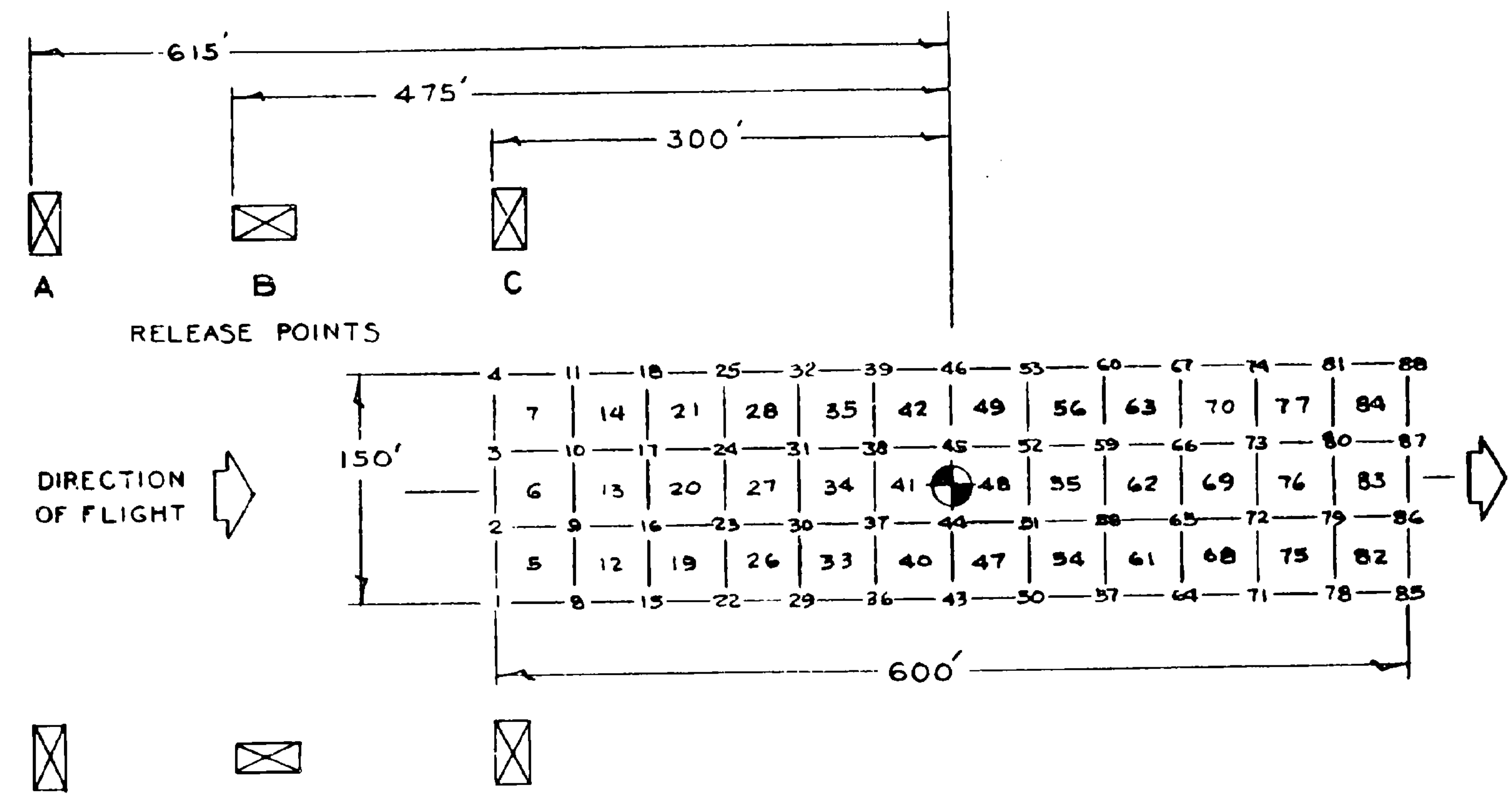


Figure 9. Target Area Grid for Aircraft Ejection Test

TABLE VIII. AIRCRAFT EJECTION TEST NO. 1

Drop	Munition Weight (pounds)	Aircraft Velocity (KTAS)	Aircraft Altitude (Feet)	Remarks
1	3.718	165	500	The drag plate was fully deployed after ejection and the munition was oriented in its downward trajectory. The munition with the drag device trailing behind impacted the ground intact. Munition malfunctioned because the drag device did not disengage the sleeve from the canister.
2	3.468	165	100	Munition functioned properly. Flechette markers impacted near center of target area. No hits were scored. Elliptic marker dispersion 30 feet wide and 60 feet long along flight path. Area coverage approximately 1410 square feet.

TABLE VIII. AIRCRAFT EJECTION TEST NO. 1 (Continued)

Drop	Munition Weight (pounds)	Aircraft Velocity (KTAS)	Aircraft Altitude (Feet)	Remarks
3	3.718	550	500	Yellow cloud of markers, marker dye and small foam plastic balls sprayed from canister after ejection. Canister with shroud line trailing behind impacted ground. Closure plate peeled off after ejection and discharged first and part of second row of markers. Munition malfunction due to ripping off by aerodynamic force of clamps and screw attachments to fasten shroud line to drag plate.
4	3.657	350	100	Munition malfunction similar to drop no. 3. The bulk of the markers were retained in the canister to ground impact. One marker impacted a canvass covered foam plastic block. The mark size was one inch in diameter.

TABLE VIII. AIRCRAFT EJECTION TEST NO. 1 (Concluded)

Drop	Munition Weight (pounds)	Aircraft Velocity (KTAS)	Aircraft Altitude (Feet)	Remarks
5	3.551	165	500	This was a repeat of drop no. 1. All aspects of the munition functioned properly. Marker dispersion covered an elliptic area perpendicular to the flight path 75 feet wide and 60 feet long. Several markers hit a Celotex board leaving a mark size one by two inches each. The area coverage was 3,540 square feet.
6	3.343	250	500	Munition operation was a partial success. Two of the three shroud attachments were torn loose but the trailing drag plate initiated munition separation and marker dissemination. Markers covered an area 410 feet long and 135 feet wide. Maximum marker concentration was in an elliptic area 180 feet wide and 55 feet long perpendicular to the flight path. Area of the elliptical area was 3,460 square feet.

TABLE IX. AIRCRAFT EJECTION TEST NO. 2

Drop No.	Munition Weight (pounds)	Aircraft Velocity (KTAS)	Aircraft Altitude (feet)	Remarks
1	3.70	165	100	Markers employed half shell of gelatin capsule inserted into flechette body. Shrouds flew off as drag plate was fully deployed. Canister started to separate as it fell earthward. Markers were dispersed from two marker cups. The others spilled the markers out on impact. Two markers hit a Celotex board leaving a 1-inch by 2-inch mark size each. Marker dispersion was spotty. Strong winds may have affected marker dispersion.
2	3.01	165	500	Fabric shroud flew off as the drag plate was deployed. Canister and marker cups impacted ground almost intact. Little marker dispersion. Drag device impacted near start of target array. Staves failed to peel off because of the nylon pins used to lock the staves to the closure plate and friction tape used to increase interference between staves and closure plate formed a tight bond.

TABLE IX. AIRCRAFT EJECTION TEST NO. 2 (Continued)

Drop No.	Munition Weight (pounds)	Aircraft Velocity (KTAS)	Aircraft Altitude (feet)	Remarks
3	3.15	550	500	Munition functioned properly. Drag device and pusher plate descended slowly. Lighter components and markers were blown out of the target area. One cup full of markers was recovered near release point. The lanyard interconnecting the drag disk and marker extractor disk snapped. No attempt was made to establish marker dispersion.
4	3.05	550	100	Munition functioned properly. Munition separation occurred as the drag device was deployed. Markers were deployed over a distance of 475 feet. Two marker filled marker cups were recovered with broken lanyards. Pink cloud sprayed out at munition separation indicating marker capsules were breaking under the aerodynamic force or by the snatch force produced by the drag plate. Marker dispersion was long and narrow.

TABLE IX. AIRCRAFT EJECTION TEST No. 2 (Continued)

Drop No.	Munition Weight (pounds)	Aircraft Velocity (KTAS)	Aircraft Altitude (feet)	Remarks
5	3.14	350	100	Munition functioned properly. Markers in the top cup were dispersed at munition separation. Three marker filled cups were recovered with broken lanyards. A green cloud sprayed out at munition separation. No attempt was made to establish marker dispersion. Motion pictures show the staves autorotating downward along with the drag device.
6	3.02	550	250	A parachute was incorporated as a drag device for this munition. The release attitude was established at 250 feet. The munition functioned properly. The parachute accelerated munition separation due to the higher snatch force. The marker cups were more closely clustered at munition separation. The lanyard snapped on all four marker cups and marker dispersion was negligible. No attempt was made to establish marker dispersion.

TABLE IX. AIRCRAFT EJECTION TEST NO. 2 (Concluded)

Drop No.	Munition Weight (pounds)	Aircraft Velocity (KTAS)	Aircraft Altitude (feet)	Remarks
7	2.99	550	250	Munition incorporated a parachute as a retardation device. Munition functioned properly, but markers were not dispersed from marker cups. Munition separation occurred simultaneously with parachute deployment. Four marker filled cups fell closely clustered together. Lanyard between drag disk and extractor plate failed in all four cups. A sustained 5-g load was applied to the munition prior to ejection to establish the retention capability of the nylon shear pin and the thin rubber closure plate. The test proved that the nylon shear pins inserted into the reinforced rubber closure plate are feasible.

SECTION VII

VALUE ENGINEERING

The value engineering program was instituted at the beginning of Phase II and was maintained to the end of the program. Value engineering was performed to achieve product improvement and reduction of fabrication costs without sacrificing munition performance. The initial result of value engineering was simplification of the munition design by eliminating a munition interlock device and a redundant pyrotechnic release system. Value design engineering evaluations after the first aircraft ejection tests resulted with a metal sleeve being replaced by a fabric shroud, and vacuum formed plastic parts replacing machined plastic parts to produce additional cost savings.

DESIGN EVALUATION

Value engineering of the initial layout drawing and detail drawings resulted with design simplification of the internal components of the munition. The original design incorporated a quick-release interlocking device to hold the munition together after final assembly to simplify handling and loading. The interlock was released at munition ejection. The design of this device is based on the ball locking principle. It consists of a thin, long 0.375-inch outside diameter plastic tube bonded to the pusher plate. The tube extends through the center of the compression column for the full length of the canister. A 0.250-inch diameter plunger rod slips through the 0.375-inch diameter tube and has a 0.750-inch diameter by 0.250-inch-thick piston at the top end under the pressure chamber. The opposite end of the plunger rod bears against the locking plug in the closure plate. At ejection the gas pressure pushes the plunger down to eject the plug. The 0.375-inch diameter plug has two diametrically opposite 0.093-inch diameter holes for the locking balls. One half of the locking balls rests in the tube and the other half bears against a 45-degree conical surface in the lower closure plate. A small plug with a 45-degree chamber is lightly press-fitted into the 0.375-inch diameter tube to hold the balls against the conical surface and interlocks the pusher plate and closure plate. This plug is pushed out at munition ejection to release the locking balls and releases the interlock between the pusher plate and closure plate.

Value engineering of the locking device and its operating sequence revealed this locking device released all constraints immediately upon ejection cartridge initiation. The interlocking device did not provide a time lapse between munition ejection and release of the interlock, and did not contribute significantly to munition function. A potential problem area was the possibility of the tube and rod bending sufficiently to prevent munition separation. The compression column, tube, plunger and rod, and plug required tolerances of ±0.001 inch. Value engineering eliminated the interlocking device and 10 detailed parts required for the interlocking device. This yielded a savings of \$98.75 per munition. In addition, the need for the + 0.001 inch tolerance for the hole through the compression column and the closure plate was eliminated.

The munition was designed to incorporate a redundant pyrotechnic release system; however, a reliability analysis of the munition system indicated that aerodynamic separation should be the prime design requirement. Efforts to develop a reliable redundant pyrotechnic release system were discontinued. This yielded a savings of development time for the pyrotechnic release system and further simplified the munition design by eliminating the parts for the redundant release system.

DESIGN IMPROVEMENTS

A value design review was performed after the first flight tests of the retarded exercise munition to establish mandatory design changes and changes to improve munition function and/or reduce costs. Mandatory changes were those required to improve munition function and to satisfy the nonhazardous requirements. These changes included reinforcing of the fiberglass drag disk and replacing the rigid plastic closure plate with a rubber closure plate.

Design changes to improve munition function and/or reduce costs included replacement of the aluminum sleeve with a fabric shroud and tear strip, modification of the pusher plate, and replacing the compression column and separator disks with plastic cups and disks.

Factors considered in replacing the aluminum sleeve with the fabric shroud and tear strips were machining time, tolerances and potential hazard of sharp edges cutting ground troops. The aluminum sleeve required machining of the internal and external diameters and milling four rectangular openings. Injection molding the sleeve from thermoplastic material was impractical for the small quantity required. The barrel staves canister produced wide variations in outside diameters of the canisters and resulted with the sleeves having interference fits on some canisters. Static compression tests of the barrel stave canisters indicated that the compressive load can be increased from 600 to 1200 pounds by wrapping 1/2-inch-wide masking tape around the middle of the canister. Additional tests using a 1-inch strip of nylon parachute material with a fabric fastener to hold the ends together produced the same results. The tests substantiated the practicality of incorporating fabric shrouds held together by tear strips as a means to restrain the staves. Other advantages of the fabric shroud and tear strips were as follows: (1) It improved performance by enabling either the aerodynamic forces or the pull of drag disk to strip the shroud from the canister (2) The shroud can be adjusted for the variations in the outside diameter of the barrel stave canister (3) The shroud and tear strip is easy to fabricate and is inexpensive (4) The fabric shroud and tear strip is not hazardous.

The pusher plate was modified to simplify the design and to provide more depth to the flanged surface in contact with the staves and to accommodate the tear strips. Changes resulting from value engineering was elimination of a boss 1.75 inches in diameter and 0.375 inch high drilled and counter-bored to accommodate the interlocking device. This change simplified the design and eliminated three machining operations.

The barrel stave canister used in the first aircraft ejection test incorporated a compression column in the center to distribute the ejection force between the

staves and compression column. Stress calculations indicated the ejection force can be distributed between the cups and the staves. A medium density polyethylene plastic cup that is 4.375 inches in diameter and has a wall thickness of 0.050 inch can bear a 1500 pound compression load. The staves wrapped with the fabric shroud can bear a 1200-pound compression force. The three 0.125-inch diameter nylon shear pins retaining the barrel stave canister requires a 465-pound force to shear the pins. The design was modified to incorporate the plastic cups to replace the compression column and separator disks. The cost trade-off was $200.00 for vacuum forming 50 plastic cups including tooling costs or $498.00 for 30 compression cylinders and separator disks assemblies. Beneficial spin-offs from the plastic cups were: (1) it reduced the average loading time per canister from 2.2 hours to 1.0 hours; (2) the cups permits the use of markers of other configurations.

RESULTS OF VALUE ENGINEERING

The value engineering program resulted with a cost reduction of $114.05 per munition between the initial layout design and the finalized design. The reduction of parts and costs are summarized in table X. The cost figures shown are cost per unit based on the set-up and fabrication of parts for 8 units. The greatest reduction in costs resulted after value engineering the initial layout drawing.

The increase in the number of parts after the first flight test was due to replacement of an aluminum sleeve with the fabric shrouds, tear strips and tear strip attachment hardware.

Value engineering recommendations after completion of the initial layout drawing and after the first flight tests were:

(1) Eliminate the interlocking device.
(2) Discontinue efforts to develop a pyrotechnic redundant release system.
(3) Replace the aluminum sleeve to restrain stave buckling with a fabric shroud and tear strip.
(4) Eliminate boss in the center of the pusher plate.
(5) Replace compression column and separator disks with vacuum formed plastic cups.

Value engineering recommendations and mandatory design changes were incorporated in the munition design for the second aircraft ejection tests. The finalized design incorporated all of the value engineering recommendations.

COST ESTIMATES

Projected costs for quantity production of the munition components were made by submitting detail drawings of the finalized drawings for cost estimates. Prices quoted by the manufacturers of plastic and rubber parts were compiled and tabulated based on the lowest bids for quantities of 100, 1,000, and 10,000. (Table XI). Additional cost savings may be realized in production by designing the shear ring and stiffener to be an integral unit, making the shroud and tear strip from .010 inch thick sheets of plastic and simplifying the pusher plate design.

TABLE X. REDUCTION OF MUNITION COST AS A RESULT OF VALUE ENGINEERING

Parts List and Cost Before Value Engineering		
	Nomenclature	Cost per Unit
1	Barrel Stave Canister Assembly of	$ 36.00
2	Staves (8)	127.50
3	Spacer Cylinder	14.90
4	Pusher Plate Assembly of	12.00
5	Pusher Plate	30.35
6	Drag Shield	68.55
7	Drag Shield Disc	19.80
8	Closure Plate Assembly of	13.50
9	Shear Ring	18.10
10	Closure Plate	28.00
11	Closure Plate Plug	14.85
12	Plug Cover	10.60
13	Locking Plug	14.85
14	Separator Assembly (2) of	8.70
15	Separator Disc (2)	9.95
16	Compression Cylinder (2)	7.70
17	Pyrotechnic Housing Assembly of	8.70
18	Separator Disc	4.95
19	Pyrotechnic Housing	14.95
20	Center Tube Assembly	8.70
21	Tube Center	15.20
22	Center Tube Flange	6.00
23	Plunger Rod Assembly	7.50
24	Plunger Rod	11.50
25	Plunger Piston	6.00
26	Plunger Disc	7.90
		$526.75
Parts List and Cost After Value Engineering		
1	Barrel Stave Canister Assembly of	$ 36.00
2	Staves (8)	127.50
3	Pusher Plate Assembly of	12.00
4	Pusher Plate	30.35
5	Drag Shield	68.55
6	Drag Shield Disc	19.80
7	Closure Plate Assembly	13.50
8	Shear Ring (Aluminum)	18.10
9	Closure Plate	28.00
10	Separator Assembly	17.40
11	Separator Disc	14.90
12	Compression Cylinder	11.55
13	Sleeve	30.35
		$428.00

TABLE X. REDUCTION OF MUNITION COST AS A RESULT OF VALUE ENGINEERING (Concluded)

Parts List and Cost After First Flight Test		
	Nomenclature	Cost per Unit
1	Barrel Stave Canister Assembly of	$ 22.00
2	Staves (8)	127.50
3	Pusher Plate Assembly of	12.00
4	Pusher Plate	30.35
5	Drag Shield Assy	68.55
6	Drag Shield Disc	19.80
7	Reinforcing Ring	21.50
8	Closure Plate	28.00
9	Shear Ring (Plastic)	18.10
10	Stiffener	11.50
11	Marker Container (4)	16.00
12	Container Cover (4)	19.80
13	Fabric Shroud (2)	8.00
14	Tear Strip (2)	7.00
15	Tear Strip Attachment Plate (2)	2.00
		$412.70

FLECHETTE MARKER

Value-design evaluation of the flechette marker body was made to establish the most economical method for fabrication of quantities required for the development and test program. Cost comparisons were made between injection molding a plastic body and heat shrinking precut lengths of heat shrinkable plastic tubing to the desired configuration. The results of the study indicated that for a quantity of 10,000 flechettes, it is more economical to use heat shrinkable plastic tubing because of the difference in the tooling costs. The amount of heat shrinkable plastic tubing to fabricate 10,000 flechette bodies is approximately 1250 feet. The cost estimates are shown in tables XII and XIII.

During the development of the flechette marker, the cost of various quantities of gelatin capsules was determined to establish a basis for cost comparison of capsules made from plastic materials. A survey of manufacturers of plastic capsules, vials, ampules and specialty containers revealed that plastic capsules of this size and shape of the gelatin capsules are not readily available. However, plastic capsules can be molded to the desired size and shape but most plastic materials are not capable of retaining aqueous fluids for a five year period. Sample quantities of epoxy based capsules were fabricated in the process laboratory. However, sufficient data has not been generated to project cost estimates for the manufacture of epoxy capsules.

TABLE XI. ESTIMATED FABRICATION COST OF MUNITION COMPONENTS

Part Name	Tooling Cost	Material	Lead Time (weeks)	Cost per unit for quantities of munitions indicated		
				100	1,000	10,000
Drag Shield	$1,380	Plastic	8	0.460	0.235	0.210
Pusher Plate	$2,280	Plastic	8	1.230	0.810	0.670
Staves (8 staves per munition)	$4,180	Plastic	6	0.180 1.440	0.180 1.440	0.180 1.440
Closure Plate	$ 640	Rubber	4	0.700	0.555	0.515
Marker Cups (4 cups/munition)	$ 125	Plastic	6	1.000 4.000	0.880 3.520	0.700 2.800
Shear Ring	$ 975	Plastic	8	0.360	0.237	0.205
Stiffener Plate	$ 580	Plastic	8	1.120	0.912	0.648
Shroud (2 shrouds per munition)	-0-	Nylon Fabric	4	1.320 2.640	0.870 1.740	0.800 1.600
Tear Strip (2 strips per munition)	-0-	Nylon Fabric	8	0.740 1.480	0.560 1.120	0.540 1.080
Total Tooling Cost	$10,160					
Total Cost Excluding Markers				13.420	10.569	9.168

TABLE XII. MATERIAL COST OF HEAT-SHRINKABLE PLASTIC TUBING

Length (Feet)	Cost Per 100 Feet	Cost Per Unit
100	$36.30	0.0303
1,000	$22.45	0.0187
10,000	$18.90	0.01575
100,000	$14.65	0.0122
Tooling $150.00		

TABLE XIII. INJECTION MOLDING COST FOR FLECHETTE MARKER BODY

Material	Quantity	Cost per Piece
Nylon 6	10,000	0.0148
	40,000	0.0134
	400,000	0.0115
	4,000,000	0.0086
ABS	10,000	0.0103
	40,000	0.0094
	400,000	0.0081
	4,000,000	0.0073
Tooling	$5,910.00	
Setup	$ 18.00	

SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are based on the program results:

(1) The munition can be product engineered for mass production to realize a lower unit cost.

(2) The munition canister can be a reuseable or a throw-away type.

(3) The inherent design features of the munition provide sufficient versatility and flexibility to utilize a variety of marking submunition configurations.

Based on the program findings, the following recommendations are made:

(1) Refine interlock between the staves and closure plate.

(2) Improve the method to separate the markers.

(3) Conduct additional surveys and experiments to process engineer a frangible marker capsule to withstand high aerodynamic forces and still shatter on impact.

(4) Perform aircraft ejection tests to evaluate the compatibility of the Retarded Exercise Munition System with markers of other configurations.

(The reverse of this page is blank)

APPENDIX I

MARKER INVESTIGATION AND DEVELOPMENT

The purpose of the marker investigation and development program was to develop an effective marking system which is economical to produce and satisfies the specified marking and nonhazardous requirements.

MARKER INVESTIGATION

A marker investigation was performed to:

(1) Optimize the marker material formulation and hue

(2) Evaluate a variety of marker configurations and to select the most promising configuration for development.

Marker Material

A number of suitable pigments and dyes were investigated to develop a dye or pigment system to satisfy the marking fluid requirements. These include FD and C dyes and flourescent and/or phosphorescent pigments. These materials, do not, possess the capability of nighttime detection without the use of ancillary equipment to excite visible light. Fluorescent materials require external stimulation to emit visible light while phosphorescent materials require exposure to radiant energy not more than several hours prior to use because of the rapid decay of the resultant emission.

Of the numerous materials, the most promising is the daylight fluorescent pigment. This type of pigment is suitable for use in systems based on aqueous, aliphatic, and most aromatic hydrocarbons. Whereas normal pigments selectively reflect a portion of the white light while absorbing and dissipating the remainder as heat, daylight fluorescent pigments transform much of the absorbed radiation into emitted light of the same hue as that of the reflected light. Thus, the reflected color is enhanced by the emitted color, producing extremely vivid colors in normal daylight conditions. The pigments are available in a variety of hues, but the two which appear to be most applicable as a marking agent are the fire orange and saturn yellow with dominant wave lengths of approximately 610 and 567 millimicrons, respectively. Results of toxicity testing indicate that the pigments are harmless, orally or by inhalation. The same study indicated the materials to be harmless percutaneously and non-irritating to the ocular tissues.

The hue of the marker material was optimized by performing human engineering studies to determine the optimum resolution of hues against white, beige and olive-green backgrounds. The wavelength most effective in stimulating the retina is approximately 550 millimicrons, and only the portion of the visible spectrum ranging from 545 to 610 millimicrons was evaluated. Spots of five colors in this portion of the spectrum were cemented to panels of the background colors -- white, beige, and olive green. Most of the tests were conducted using the olive green (OG) since ground troops participating in the wargames for which the munition is intended will probably be wearing the fatigue uniform. The beige panels used closely match the "suntan" uniform.

Observers were asked to rate the visibility of the color spots against the varying backgrounds under natural lighting conditions of full sunlight and full shade, and artificial lighting ranging from approximately 50 foot-candles down to 4 foot-candles.

Inspection of both curves in figure I-1 indicates that the best resolution occurs at 567 millimicrons. However, in the full sun any hue in the range of 560 to 590 millimicrons is satisfactory. When viewed in full shade, fire orange at 610 mm is as easily resolved as saturn yellow at 567 mm.

The graph shown in figure I-2 shows the resolution of the same portion of the visible spectrum against the same OG background. Under each of the lighting conditions tested, preference was shown for the 567-mm wavelength, and at the 4-foot-candle level selection of the wavelength was unanimous.

The following is a tabulation of the preferred colors and wavelengths in millimicrons against the three backgrounds tested under all lighting conditions.

Artificial Light Level Foot-Candles	White	Background Beige	Olive Green
48	Fire Orange 610	Any color tested 567-610	Yellow 567
20			Yellow 567
4	Fire Orange 610	Yellow 567	Yellow 567
Natural Lighting			
Full Sun			Yellow 567
Full Shade			Yellow 567 or Fire Orange

It was concluded that regardless of the vehicle selected, the pigment must be permanently suspended or emulsified in a mixture having a viscosity of 60,000 centipoise or less.

Several water soluble resins were evaluated as thickening compounds. The use of one of these resins will result in a permanently stable emulsion or suspension whose viscosity is only slightly affected by temperature. The viscosity of the resulting system can be varied over a wide range, while flow characteristics are excellent after a shear stress exceeds a characteristic minimum value. The resins can be used to thicken a variety of solvents and solvent mixture systems.

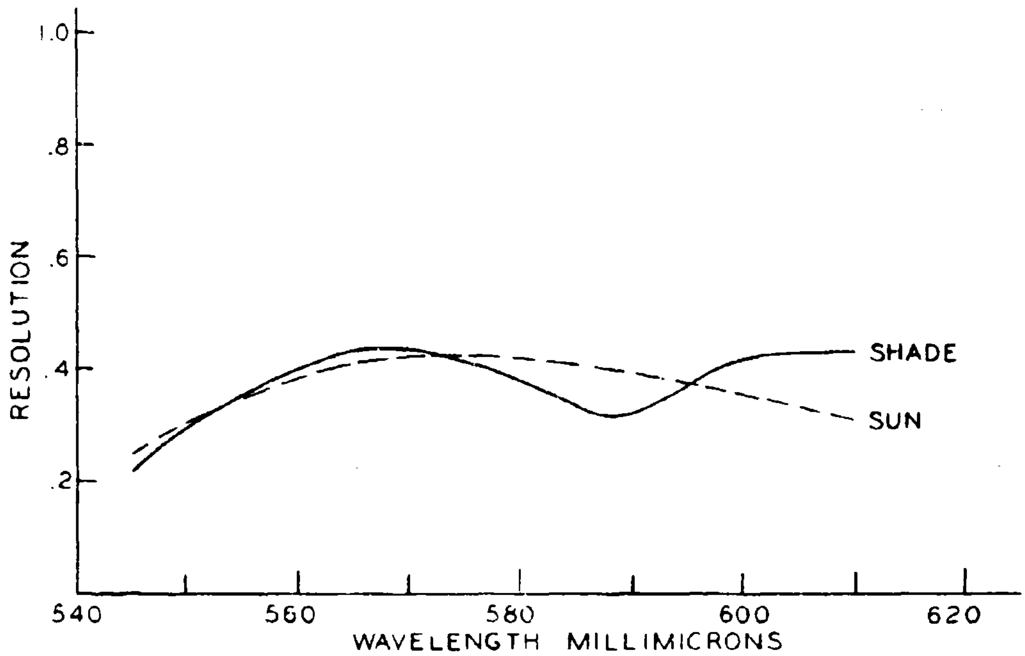


Figure I-1. Average Resolution Against An Olive-Green Background

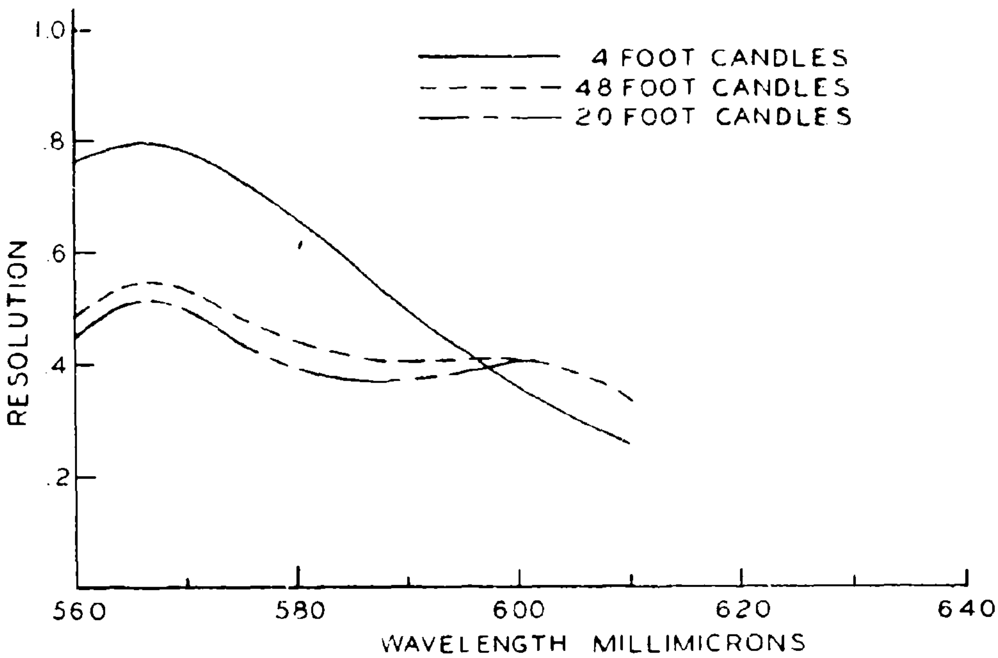


Figure I-2. Average Resolution Against an Olive-Green Background Under Various Lighting Conditions

The data generated in the marker test program precluded the use of a dry marking agent and a liquid system was formulated. Marker material investigations, toxicity studies, and the human engineering study narrowed down the candidate components to those which were included in the final mixture. A sample was submitted for toxicological and dermatological testing.

The mixture is composed of the following percentages of ingredients of weight:

(1) Vehicle 88.0 percent

1, 2 - Propanediol (propylene Glycol)

(2) Pigment 10.0 percent

Saturn Yellow A-17 first choice
ARC Yellow A-16 second choice
Blaze Orange A-15 third choice

Each of the pigments is a "Day-Glo" pigment available from Switzer Brothers, Inc.

(3) Wetting Agent 1.0 percent

Rohm & Haas Co. Triton X-100

The wetting agent improves the dispersion of the pigment in the vehicle and assists in the subsequent removal of the marks from the skin and fabrics.

(4) Thickening Agent 0.5 percent

Carbopol 934

Carbopol 934 is available from B.F. Goodrich Chemical Company. Its use results in the permanent suspension of the pigment in the vehicle without significant effect on the shear and flow of the mixture.

(5) Neutralizer 0.5 percent

Triethylamine

A weak amine base is required to neutralize the slight acidity of the carbopol resin to ensure maximum storage stability. The pH adjustment, need not be exact since stable mixtures are possible over the range of pH from 5.5 to 11.0.

Components must be added in a certain order, to assure homogeneity and reproducibility of the mixture. Formulations are prepared in the following way:

Mixture A (Solid Components)

Pigment	10.0 grams
Carbopol 934	0.5 gram

Prepare mixture of the dry ingredients; then screen to break up large agglomerates.

Mixture B (Liquid Components)

Propylene Glycol	88.0 grams
Triton X-100	1.0 gram

Combine the two miscible liquids and heat to 65° Centigrade. Sprinkle the dry mixture A into the vortex of the agitated liquid mixture B. After the addition is completed, reposition the mixer to achieve agitation, without vortexing, until a thin, lump-free dispersion is attained. Add 0.5 gram of the amine neutralizer with continued stirring.

Prolonged centrifuging of the suspension formed in accordance with the above procedure results in no evidence of sedimentation of the pigment. A sample prepared to observe sedimentation on longterm storage showed no indication of sedimentation at the end of the program.

The formulation of the marker material was finalized before the marker configuration was selected and before the method for encapsulating the marker material had been established. The flechette-type marker utilized gelatin capsules as an interim method to encapsulate the marker material until a more suitable technique and material was established. The gelatin capsules had a tendency to soften 3 to 4 days after the capsules were filled.

Investigation of this phenomenon disclosed that the Propylene Glycol used in the marking material caused the gelatin capsule to soften. One recommendation to correct this problem was to revise the marker material formulation utilizing Dowanol 112-2 as a substitute for Propylene Glycol and to treat the gelatin capsules for 48 hours at 50°C in a closed container in the vapors from a 37 percent Formalin solution. The capsule thus treated may be filled with the marker material and sealed with Collodion or a band of hot gelatin to close the joint around the waist of the capsule to avoid leakage.

Marker Configuration

Evaluation of marker configurations were made after engineering analysis, fabrication and testing were performed on wet and dry marker configurations. The wet types include basic shapes, which could be flocked for liquid retention, encapsulated porous materials, modified flechettes, vaned cylinders and maple seed carriers. The dry carriers include open-celled foams impregnated with dry pigments, encapsulated powders, and pelletized powder pigments.

Drop testing of representative samplings of each marker configuration was conducted from a 120-foot drop tower to determine the dispersion, mark size and visibility. The results of the tests indicated that the dry markers had good dispersion, but poor marking ability. The wet markers showed good and bad dispersion as well as good and bad marking ability, depending upon the marker configuration. Three of the better markers were the modified flechette configuration, vaned cylinder and maple seed type. A description of each marker configuration and the respective test results follow.

Basic shapes consisting of cubes, cylinders, and rectangular prisms with aspect ratios ranging from 1/1 to 5/1 and were made from wood or open-celled foam materials. Basic shapes were tested in the drop tower program even though preliminary tests indicated that a more sophisticated shape would be required. The saturated foam shapes showed very good marking capability but a nearly vertical trajectory. The saturated wooden shapes (figure I-3) showed a more desirable flight path but impacted at a low velocity and displayed poor marking capability.

Encapsulated carriers consisted of small heat-sealable plastic bags, each containing either a cotton ball or a 1- by 1- by 0.25-inch piece of open-cell foam (figure I-3). The thin plastic bag was not intended to rupture on impact but was perforated to permit escape of the marking material on impact. The objective was to retain sufficient marking material even if the bag ruptured on munition function to mark impacted personnel. The drop tests indicated good dispersion and satisfactory marking capability with either type (cotton or foam) of encapsulated marker.

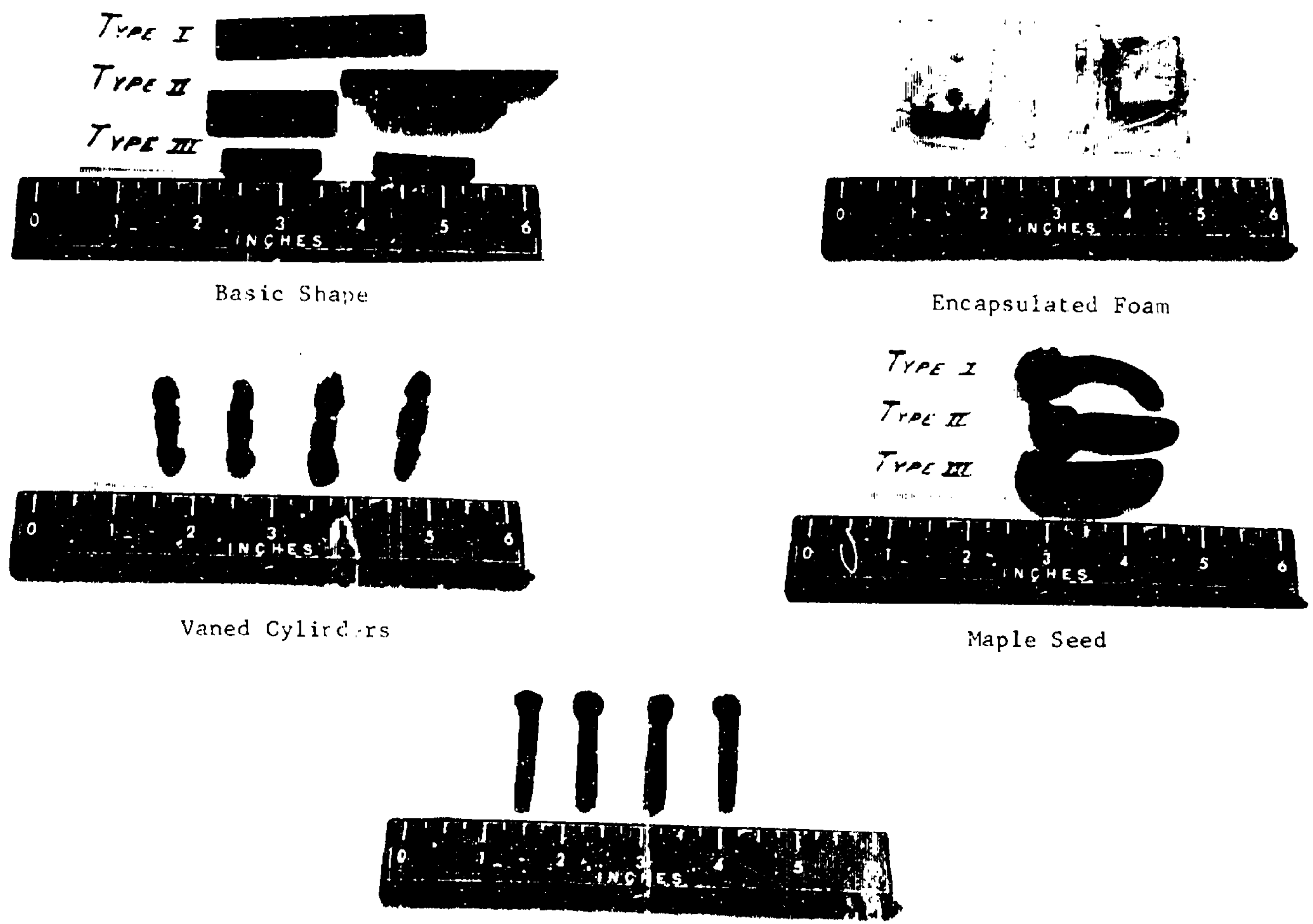
The modified flechettes (figure I-3) were approximately 1.5 inches in length by 0.25 inch in diameter. The absorbant material used was cotton, and the shank of the flechette was thin-walled plastic tubing. The fins were formed by crimping the plastic tubing. Drop tests showed satisfactory dispersion coupled with excellent marking ability.

The vaned cylinders fabricated for the drop tests are shown in figure I-3. The body of the marker was made from thin-walled plastic tubing and the absorbent material was cotton. The markers showed poor dispersion and fair marking potential.

The maple seed configuration (figure I-3) showed good dispersion and satisfactory marking.

Carrier containing or consisting of a dry pigment offers the following advantages over a saturated marker: (1) it is considerably more affected by wind resulting in a more desirable flight path; (2) preclude the necessity of a freezing point depressant required in a liquid mixture; (3) facilitate formulation of the marking material since it would be a one or at most, a two-component system compared to a minimum of about five components for the wet system. Several specimens were prepared by filling commercially available gelatin capsules with loosely-packed pigments. While these markers exhibited an excellent trajectory, flipping and tumbling while falling, the impact velocity, from a height of 60 feet was not sufficient to fracture the capsules. Capsules with 1/16-inch diameter holes in each end were tested with the expectation that sufficient material would be discharged on impact to mark a human target. However, the capsule emptied its content in the drop yielding a virtually intact plume of pigment from the platform, at 60 feet, to the ground.

The use of a porous material impregnated with dry pigment did not have much merit since the marks produced were only slightly larger than the impacting surface of the marker. In this case, the volume of the SUU-13/A canister would be limited to approximately 100 one-cubic-inch markers, a number too small to mark the required 30 percent of random troops in a 1500-square-foot area.



Basic Shape

Encapsulated Foam

Vaned Cylinders

Maple Seed

Modified Flechette

Figure I-3. Marker Configurations

The use of pelletized pigment was investigated. However, the least densely consolidated pellets were too durable to impact reliably when dropped from 120 feet. The ability of pellets of this type to withstand the dynamic ejection force is doubtful.

The marker configurations were evaluated by establishing a list of selection criteria to compare the merits of each marker relative to all the marker types investigated. The ratings of criteria were performed subjectively with the exception of dispersion and mark visibility, whose ratings were a result of test data analysis. The comparison of the marker configurations evaluated is shown in the table on the next page.

Ratings were assigned values for each attribute with 10 being the best performance and 0 the poorest. The composite rating is a summation and the normalized is a quotient of each composite rating divided by the highest composite rating.

All of the markers tested will satisfy the troop safety requirements based on the kinetic energy generated by their mass and their predicted terminal velocity. Analysis of predicted impact velocities and unit impact energies of the marker configurations indicated that all of the markers investigated has unit impact energies of less than 8 foot-pounds per square inch.

The flechette configuration was recommended for further development during Phase II based on the investigation performed on the marker configurations.

MARKER DEVELOPMENT

To develop a low-cost method to produce the flechette-type marker, investigations were made in the fabrication of injection molded flechettes, making flechette bodies similar to golf tees, vacuum forming flechettes, using wax molds, and heat shrinkable plastic tubing. Studies of fabrication techniques and associated tooling costs for quantities required for this program indicated the best option was the use of thin plastic tubing. This tubing could be configured to the desired flechette body shape with the marking material encapsulated in a frangible capsule. The tubing was configured to the desired shape by using heat shrinkable plastic tubing which was placed on a mandrel and heatshrunk to shape. A deviation was made in the flechette configuration in which a cone-shape tail section was incorporated instead of a finned tail section. A check of the flechette stability using a cone instead of fins indicated that the cone would function equally as well.

The flechette marker (figure I-4) incorporates heat-shrinkable plastic to form the flechette body. The nose is formed from 80 pores per lineal inch (ppi) polyurethane foam which is inserted into the flechette body. A film plastic cap is placed over the foam plastic nose and heat-sealed to the flechette body. The marker dye solution is injected into the nose from the rear of the flechette and sealed by a plastic plug. An alternate method for encapsulating marker dye solution in the foam plastic nose was dip forming and sealing a paraffin cap to the body.

MARKER CONFIGURATION EVALUATION

MARKER TYPE	Troop Safety	Dispersion	Mark Visibility	Predicatable Trajectory	Area Coverage	Percentage of Troops Marked	Foliage Penetration	Composite Rating	Normalized Rating
<u>Wet</u>									
Basic Shapes									
Flocked Wood	10	8	2	4	8	7	4	43	6.8
Saturated Foam	10	2	8	4	2	7	4	37	5.9
Encapsulated Foam	10	6	6	6	6	7	4	44	7.0
Modified Flechette	10	7	10	10	7	10	9	63	10.0
Vaned Cylinder	10	4	6	7	4	10	6	48	7.6
Maple Seed	10	8	6	4	8	10	8	54	8.6
<u>Dry</u>									
Impregnated Foam	10	7	1	4	7	1	4	34	5.4
Encapsulated Powders	10	7	0	4	7	0	4	32	5.1
Pellets	10	7	1	4	7	1	4	34	5.4

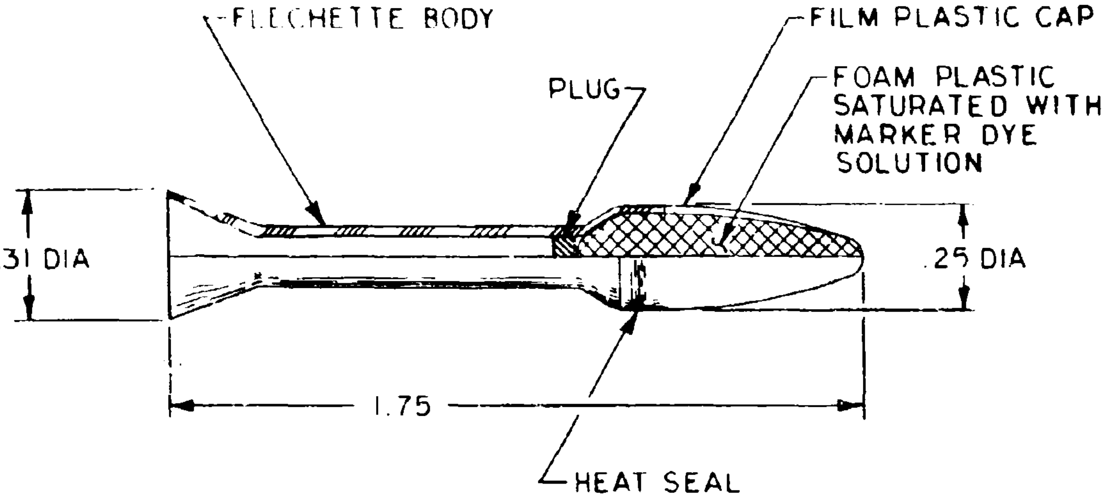


Figure I-4. Flechette Type Marker

Another approach in forming the marker nose section was to use a capsule made with high temperature wax to encapsulate the foam marker saturated with the dye. On the basis of the results obtained by wax dipping the nose of the flechette markers, it was concluded that a carefully controlled forming process would be required to produce a smooth configured nose section for the marker.

In the drop tests, flechettes using frangible and film plastic nose caps were dropped from a height of 60 feet upon a concrete surface. A comparison of the impact mark size produced by the two types of nose caps clearly established the superior marking quality of the frangible nose cap over the flexible film plastic nose cap. Based on the test results, the flechette markers were designed to incorporate a frangible nose to encapsulate the marker dye. The following design objectives were established to define clearly the requirements for the frangible nose cap:

(1) The nose cap must be capable of withstanding the impinging aerodynamic force at 550 knots.

(2) It must shatter on impact.

(3) It must be economical, easy to fabricate or readily available.

The primary goal was to secure a nose cap which could be utilized immediately to prove design feasibility, followed by a search for a suitable material.

The gelatin capsule was selected as an interim nose cap since it was readily available, very economical and exhibited some of the desired physical characteristics. In addition, demonstration of the design feasibility of the capsule approach would greatly expedite development of the flechette marker. From a material standpoint, similar capsules could be made from nitrocellulose or epoxy resin.

The resulting flechette marker configuration incorporating the gelatin capsule is shown in figure I-5. The foam plastic filler inserted into the gelatin capsules with the marking material was eliminated. Tests of the flechette markers using gelatin capsules with and without the foam plastic filler demonstrated that superior mark size was produced by capsules without the foam plastic filler.

The flechette marker shown at the top in figure I-6 incorporate only a half shell of the capsule to eliminate the double wall thickness in the area where the two half-shells overlap. A configuration for an injection molded marker is shown at the bottom of figure I-6.

Vendor and material survey performed to find a suitable replacement for the gelatin capsule revealed that frangible plastic capsules similar to the gelatin capsule are not readily available.

Manufacturers of gelatin capsules indicated that development work has been done to manufacture plastic capsules. However, they are not manufacturing plastic capsules at present and would not consider manufacturing plastic capsules until there is a demand for extremely large amounts.

A program to develop a process for fabricating pilot quantities of capsules from epoxy base material was initiated. Tests with the epoxy shell indicated these capsules to have the desirable quality of being rigid enough to maintain its structure but brittle enough to shatter on impact. Sufficient data was not accumulated at the end of this program to project any cost estimates for the manufacturer of epoxy capsules.

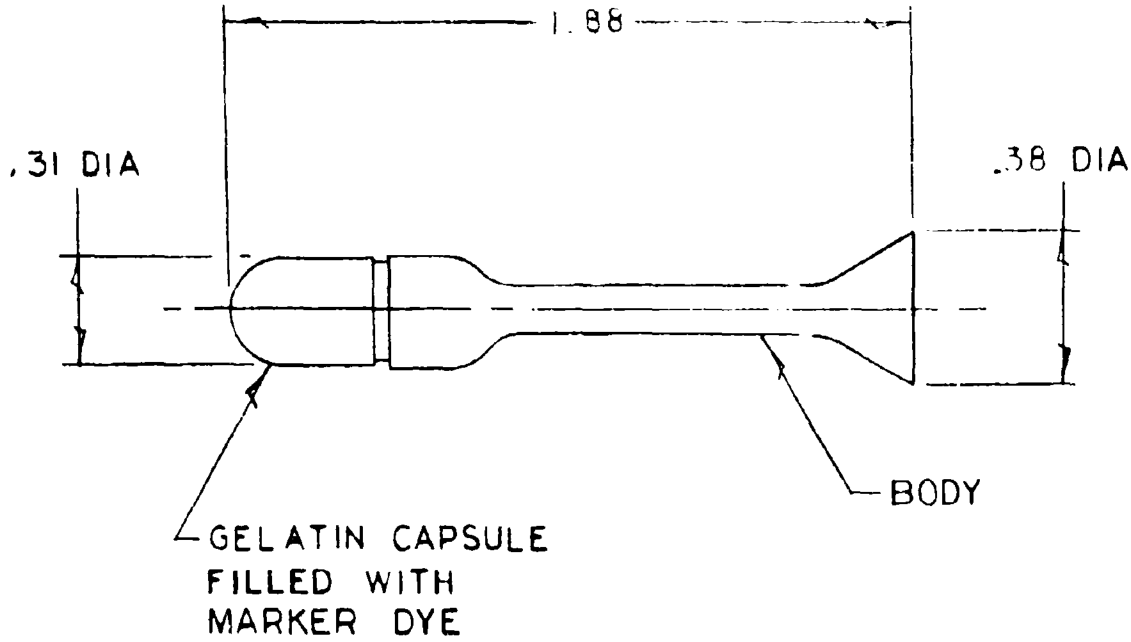


Figure I-5. Flechette Marker

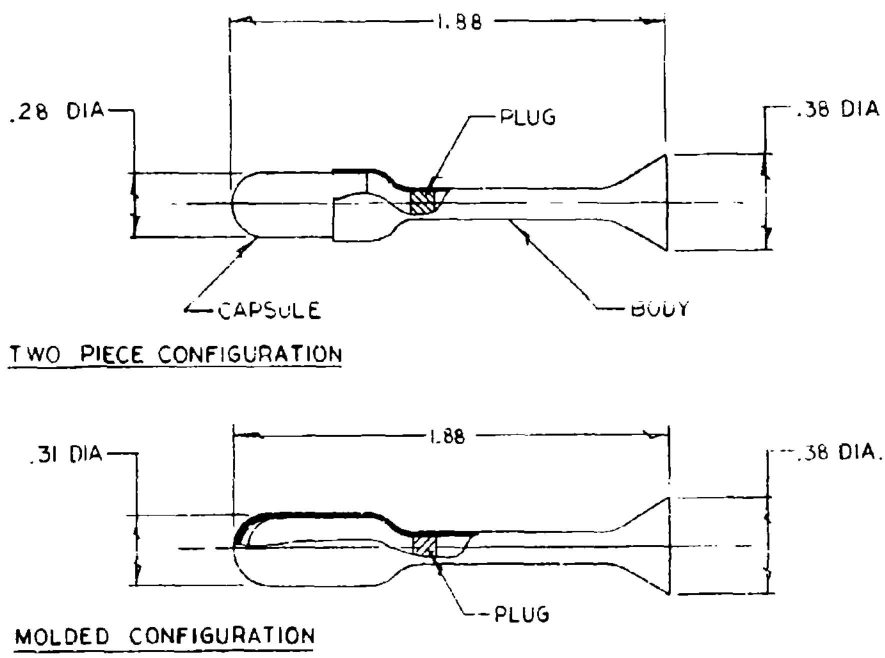


Figure I-6. Proposed Flechette Marker Configurations

APPENDIX II

MUNITION CONCEPT INVESTIGATION, SELECTION ANALYSIS, AND AERODYNAMIC ANALYSIS

MUNITION CONCEPT INVESTIGATION

A variety of munition concepts were investigated during Phase I to evaluate the feasibility of each concept relative to aircraft and troop safety, design and development costs, and munition performance. The three candidate concepts selected for a comparison of their relative merits were: Concept A, a parachute retarded munition; Concept B, an autorotating vane concept; and Concept C, a barrel stave concept. A brief description of each concept and their respective functional diagrams are presented in the following pages.

Near the conclusion of Phase I, munition design concepts were developed in sufficient detail to conduct feasibility tests of the three concepts from the 120 foot tower. The tests demonstrated concept feasibility of all three concepts with Concepts A and C performing better than Concept B.

The munition concept analysis and investigation established Concept C, the barrel stave concept, as the most promising of the three. Final selection of Concept C was based on rating each concept relative to the other in its ability to meet aircraft and personnel safety, design and development, and munition operation criteria.

Concept A

Design

The parachute retarded munition concept (figure II-1) consists basically of an outer case, a marker container, a bore rider release device, parachute, and a parachute cover plate. The outer case is formed from lightweight plastic tube capable of withstanding the aerodynamic and ejection forces. The marker container is formed by two end plates separated by three rods equally spaced or by a single tube in the center. A seal between the base of the inner container and the outer shell forms a leakproof assembly until ejection. The parachute cover plate houses the parachute and protects it from the ejection blast. A mechanical or a pyrotechnic bore rider release device is incorporated in the design to provide a redundant system in the release and dissemination of the markers. The ejection force is transmitted through the outer case to the base of the marker container to shear the munition free from the SUU-13/A canister and to break the seal.

Operation

Upon ejection the parachute is deployed after the munition clears the dispenser (figure II-2). The snatch force of the parachute triggers a latch which extends the marker container and the inertial and gravitational forces disseminate the markers from the container. The markers, being lightweight, will strike the target area with low impact energy. The remaining hardware descends to the ground retarded by the parachute to a nonhazardous velocity.

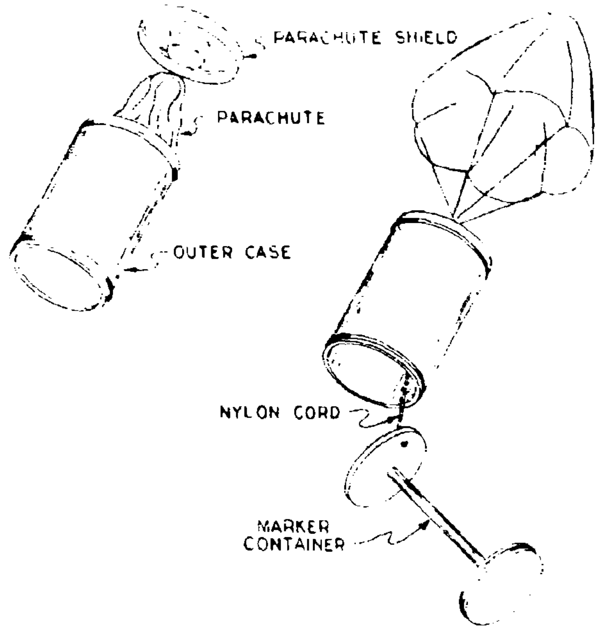


Figure II-1. Parachute Retarded Munition, Concept A

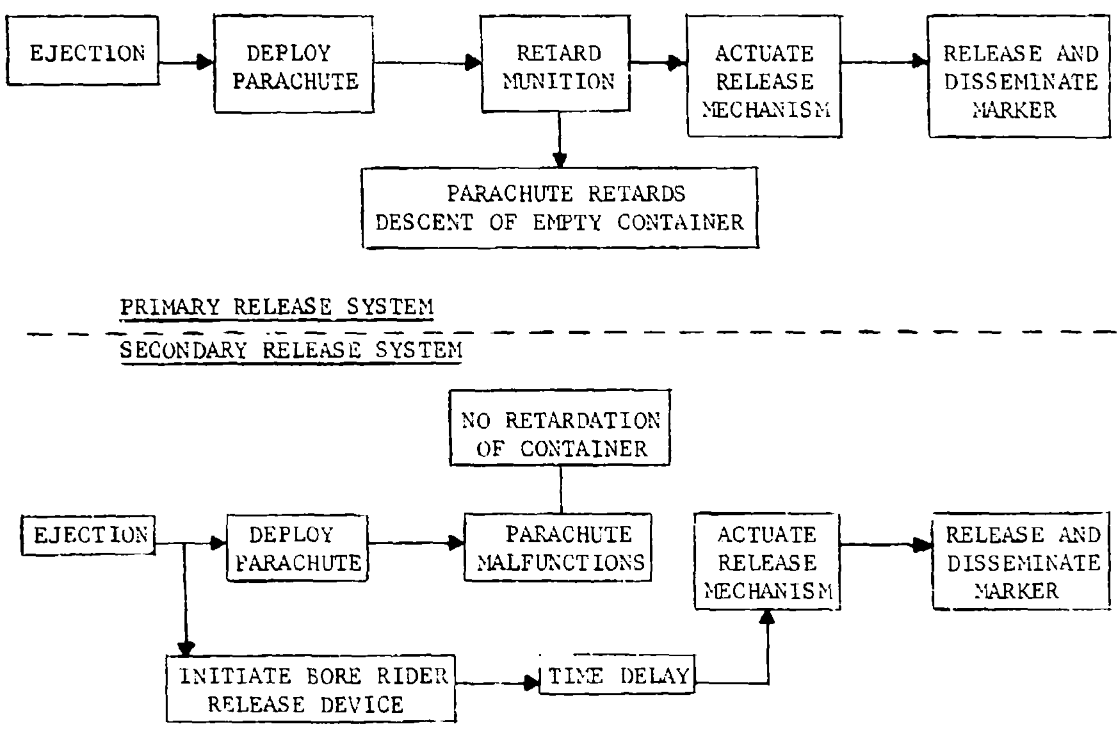


Figure II-2. Sequence of Operation of Concept A

In the event the parachute fails to open and trigger the device to extend the marker container, the bore rider release mechanism automatically extends the marker container. The aerodynamic and gravitational forces acting on the container disseminate the markers to empty the marker container before it strikes the ground. However, this only assures that an empty container impacts the ground that may or may not be partially retarded. To avoid this condition, consideration was given to include a mild burster charge to destroy the container while it is still airborne.

<u>Concept B</u>

Design

The autorotating vane concept, (figure II-3) incorporates drag vanes attached to both end plates. The vanes form the outer structure of the munition system and are held in the closed position by a wind tab or end caps. The marker units are contained within the drag vanes by a frangible case which is designed to tear apart as the vanes begin to open or when it is subjected to aerodynamic forces. A fiberglass inverted hat-shape plate is placed on the top of the container to function as a pusher plate at ejection and to protect the hinge area. The drag vanes are made from injection molded polycarbonate plastic and are spring-loaded to initiate rearward vane rotation.

The hinge on each vane is offset from the centerline to incorporate a slight pitch to the vane. Each vane rotates about its hinge base 120 degrees before stopping against an elastic snubber. When the vane returns to its normal position at 120 degrees, it induces a spin to the end plate and autorotates down at a low velocity. The marker units are dispersed the instant the frangible case is torn apart. The dynamic forces created by the tumbling action of the container should impart a force on the markers to disperse the markers.

Operation

When the munition is ejected (figure II-4) from the dispenser, the air striking the munition blows the end caps (or wind tab) off and flips the vanes on the upper plate backwards, causing it to autorotate and decelerate. The lower plate with the vanes continues in its trajectory until aerodynamic forces flip it over to initiate autorotation and deceleration. The frangible bag is torn apart by the impinging air and disperses the markers. The autorotating vanes descends slowly.

In the event the caps or wind tab fail to release the vanes, a secondary bore ride release device initiates a mild propellant charge to automatically release and extend the autorotating vanes to decelerate its downward descent.

<u>Concept C</u>

Design

The barrel stave concept (figure II-5) employs the barrel stave principle in which the container is formed by 8 or 16 preformed side sections or staves and lightweight end plates hold the staves in place.

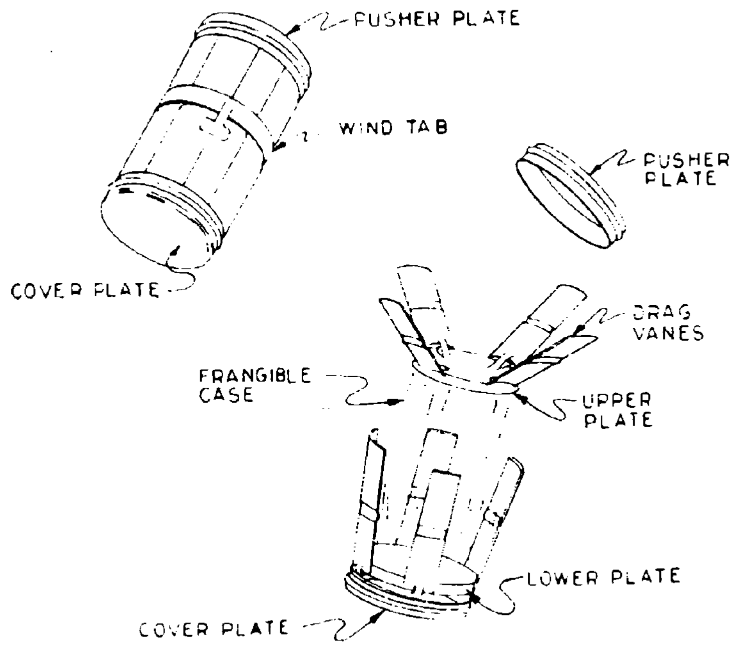


Figure II-3. Autorotating Vane, Concept B

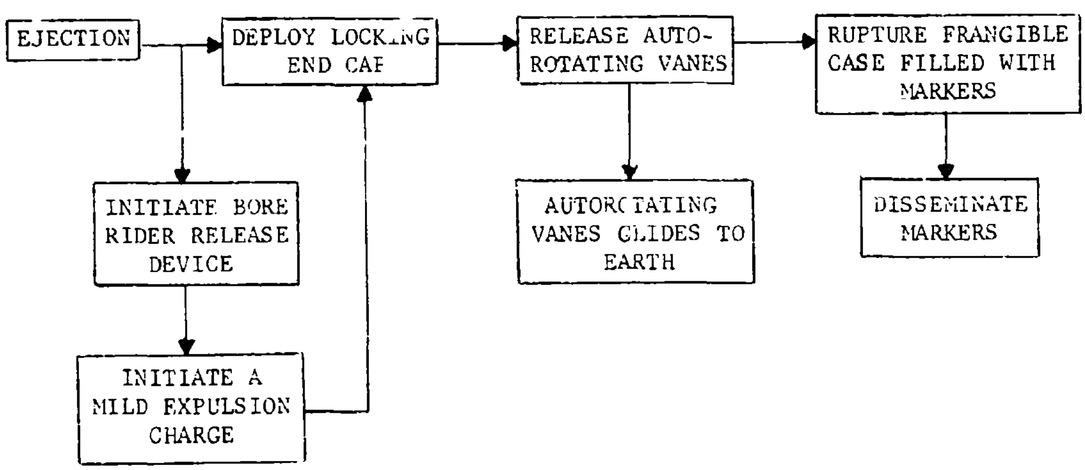


Figure II-4. Sequence of Operation of Concept B

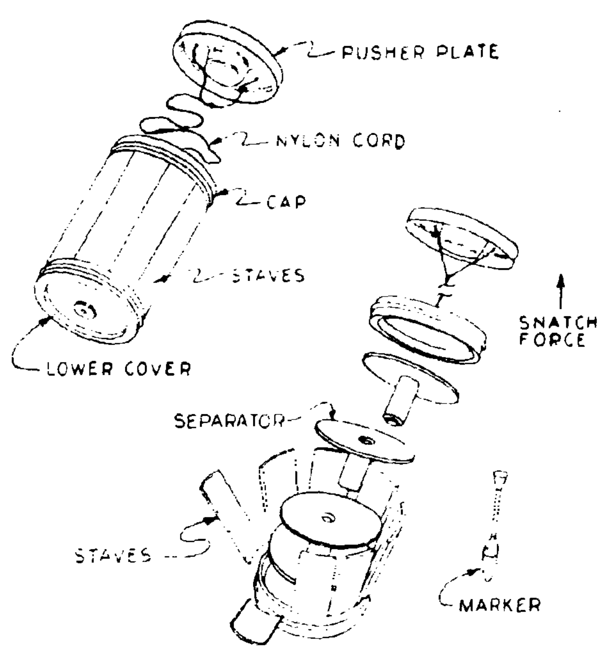


Figure II-5. Barrel Stave, Concept C

Four rows of markers are packaged directly into the container and are separated by separator disks or prepackaged in frangible bag and packed into the container. A fiberglass inverted hat-shaped pusher plate is placed on the top of the container to act as a pusher plate as the munition is ejected. This plate is connected to the upper end plate by a nylon cord and functions as a drag device.

Operation

After ejection from the dispenser (figure II-6), the pusher plate separates from the outer container due to the difference in the ballistic characteristics of the two bodies and the nylon cord feeds out until it is fully extended. The resulting snatch force pulls the top plate off of the container and the staves fly off simultaneously dispersing the markers. The lightweight staves rotate and descend slowly. The drag device retards the cap while the lower cover free falls down.

Feasibility Tests

Concept feasibility models were ejected from a 120-foot drop tower to demonstrate feasibility and aerodynamic predictions of these concepts. Munition opening and marker dispersion began approximately 30 to 40 feet from the point of ejection. The parachute retardation was effective after 30 feet of travel, the staves of the barrel stave container began autorotation after 40 feet of travel and munition opening occurred. The upper drag vanes of the autorotating concept began autorotating after 40 feet of travel and munition

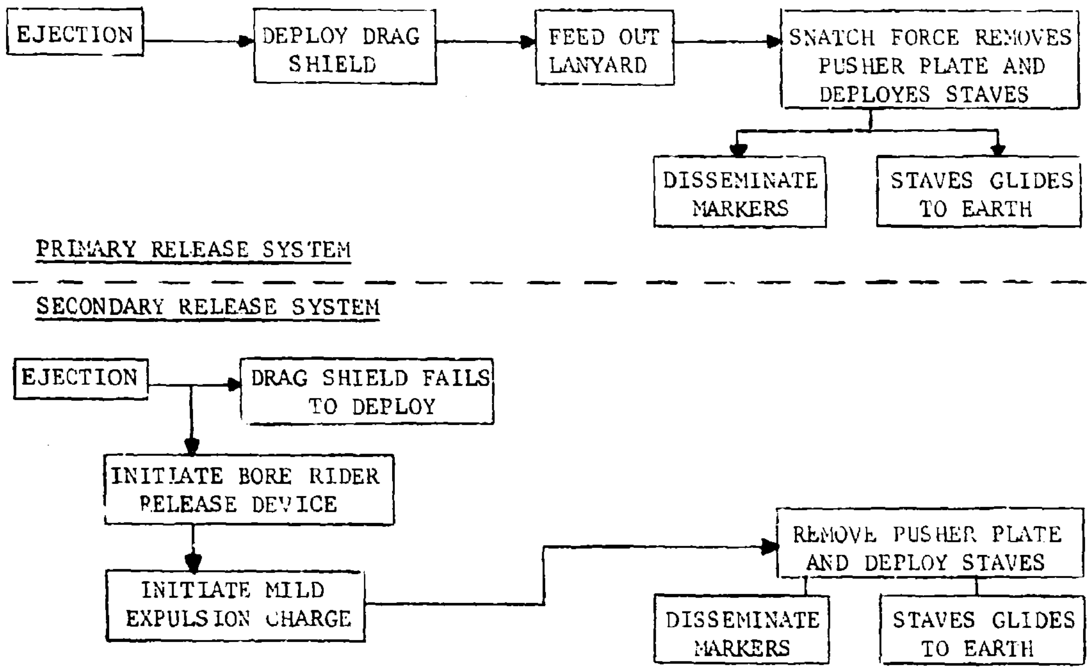


Figure II-6. Sequence of Operation of Concept C

opening occurred. The lower drag vanes traveled an additional 50 feet before beginning to autorotate. The average impact velocity of the parachute retarded container and barrel stave container was approximately 45 fps; the ejection velocity was 120 fps.

To simulate munitions filled with markers, each model was filled with more than 150 markers representing spheres, maple seed type markers and flechette markers. The markers were dipped and thoroughly saturated in a sample formulation of the marker dye solution and loaded into the test models prior to ejection. Films of the tests only recorded overall performance of the munition. Marker dispersion was not readily discernable in the films. The wet markers did not disperse readily but tended to cling together after being released from the container.

SELECTION ANALYSIS

The following technical discussion describes in detail the methodology analyses and data derived and used in support of a concept choice, also included is a list of the selection criteria.

Based on the analytical and subjective analyses performed, the Barrel Stave Concept (designated Concept C) was selected as the munition concept to be developed during Phase II.

Selection Criteria Methodology

The technique used for evaluating and selecting the best concept was to establish a list of criteria and include considerations for safety, design, development and manufacturing costs, and munition performance as the basis for comparing the merits of each weapon.

The selection criteria list (table II-1) was divided into three groups. Group A, Safety, lists criteria pertaining to aircraft safety and ground personnel safety. Group B, Design and Development, lists criteria pertaining to the mechanical design of the munition, development time relative to cost. Group C, operational, lists criteria pertaining to munition function, reliability, maintainability and dissemination of markers.

TABLE II-1. CONCEPT SELECTION CRITERIA

Group	Weighting Factor
A. Safety	
1. Aircraft	1.0
2. Personnel	1.0
B. Design and Development	
1. Interchangeability	.3
2. Flexibility	.6
3. Complexity	.8
4. Munition Cost	.9
5. Development Cost	.6
C. Operational	
1. Reliability	1.0
2. Maintainability	.5
3. Realism (area coverage)	.8

The selection criteria were examined subjectively for order of importance. A weighting factor was assigned to each with 1.0 as the highest value, decreasing to 0.1.

In the analysis, each concept was rated relative to the other in its ability to meet the criteria.

In rating the concepts the following procedure was used:

(1) A nonacceptable/acceptable cutoff point was determined which meets or exceeds the specifications, standards or design concepts. On a continuum scale from 0 to 10, a cutoff point rated as barely acceptable is represented by a score of 3.0. A score of 6.0 was considered as the mean and rated as good.

(2) The concepts were arranged on a scale from "best" to "poo ' and are acc^ptable if represented by a score of 10.0 to 3.0

(3) Five raters were engaged to perform separate and independent analysis of the criteria. Each rater was given a clear unequivocal conception of the criteria on which he was to evaluate the concepts and all raters were given copies of the concept, drawing specifications, and other explanatory material, as well as viewing motion pictures of the tests.

The rating submitted by each rater was compiled and the mean rating was obtained. This mean rating was weighted by multiplying the corresponding weighting factor (table II-2) to give a composite rating f(R). The total of these composite ratings for each concept shows the working of each.

Analysis

The following paragraphs discuss the selection criteria and their factors, and the analysis thereof.

Aircraft Safety

Aircraft Safety in any concept considers those features which assure the ejected munition and any associated components clear the aircraft. The munition maintains its structural integrity from ejection until deployment of the retardation device.

In this evaluation Concept A was rated highest because the cylindrical outer container can easily withstand the large ejection force and airloads at high release velocities. Another factor is the effect of hydrostatic pressures under high G forces at ejection, particularly in the case where the markers are immersed in the marker dye solution. The cylindrical container can easily withstand the hoop stress resulting from the hydrostatic pressure. Concept B and Concept C require a strap around the periphery of the container to restrain the vanes or staves from bulging outward under the hydrostatic pressure. The vanes or staves may also require a stiffening member to withstand the columnar loading at ejection. The three concepts were rated 8.7 for Concept A, 8.0 for Concept B, and 7.7 for Concept C.

Personnel Safety

The features given consideration in the evaluation of personnel safety were the energy level at impact, the type of impact and canister component impact attitude that personnel can withstand without bruising. An assumption was made that the markers were completely disseminated prior to impact. The energy level

TABLE II-2. SELECTION CRITERIA RATINGS

	Weighting Factor	Concepts A R	A f(R)	B R	B f(R)	C R	C f(R)
1. Aircraft Safety	1.0	8.7	8.7	8.0	8.0	7.7	7.7
2. Personnel Safety	1.0	7.3	7.3	7.7	7.7	8.3	8.3
3. Interchangeability	.3	6.3	1.9	6.3	1.9	6.3	1.9
4. Flexibility	.6	6.7	4.0	8.2	4.9	8.3	5.0
5. Complexity	.8	7.0	5.6	8.0	6.4	9.3	7.4
6. Munition Cost	.9	5.5	5.0	7.5	6.8	8.8	7.9
7. Development Cost	.6	8.0	4.8	6.7	4.0	7.0	4.2
8. Reliability	1.0	8.0	8.0	8.5	8.5	8.3	8.3
9. Maintainability	.5	9.8	4.9	9.0	4.5	9.2	4.6
10. Realism	.8	7.8	6.2	9.7	7.8	9.7	7.8
Total R		75.1		79.6		83.9	
Total f(R) Composite			56.4		60.5		63.7

at impact would be a function of the aerodynamic characteristic of the retardation device. The parachute concept would approach a near vertical descent with its empty container attached to it. The autorotating van should also approach a near vertical descent; however, the possibility of the rotating vanes slashing personnel at impact would be a factor to consider. The barrel staves would rotate and descend in a spiraling glide path and should impact at a low impact velocity. Any change in attitude of the stave may cause the stave to impact on one end which would increase the unit impact energy considerably.

Concept C was rated highest (8.3) followed by Concept B rated 7.7 and Concept A rated 7.3.

Consideration was not given to the markers because the markers used would be the same in each concept.

Design

Interchangeability

Interchangeability considers the capability to readily adapt the munition designed for use with the SUU-13/A dispenser with the TFDM dispenser. This takes into account the basic munition configuration and the relative ease in which it can be used in both dispensers.

All concepts were given an equal rating since the basic munition configuration required for each dispenser is not compatible. Secondly, it was noted in reviewing information available on the TFDM dispenser that the Air Force is in the process of, or has already, developed an adapter for the TFDM dispenser to utilize munitions designed for the SUU-13/A dispensers.

Flexibility

Flexibility gives consideration to the inherent design qualities that enable changes to be incorporated without requiring drastic or costly redesign or changes affecting the basic munition concept. This can be an important factor if changes are required to enhance performance of the munition or to correct design weaknesses which may become apparent during development testing.

In this evaluation Concept C was given the highest rating followed closely by Concept B and then by Concept A. The simplicity of Concept C makes it relatively easy to incorporate changes without affecting other components. In Concept B, the need for hinging of the blades and associated hardware increases the complexity of the design. Thus, in incorporating any changes, greater effort may be required to limit the effect of the change on other components. Concept A was considered to be the most complex of the three concepts. Thus any changes to be incorporated may affect several components.

Complexity

Complexity was evaluated in terms of the total number of parts required, the difficulty to fabricate the parts, the number of subassemblies, and ease of assembling the munition.

Concept C was given the highest composite rating, 7.4 since it consists basically of two end plates, the staves and the drag shield with its interconnecting cord. The staves are identical in size and shape. All parts are made from plastic except in certain areas where metal parts may be required. Concept C is easy to assemble.

Concept B was rated 6.4. The need for the hinges for the autorotating vanes makes the only difference in complexity. Concept B consists of a closure plate, pusher plate, hinge plates and the blades. The blades are identical in size and shape. The only parts to be made from metal are the hinges and the shear ring. Plastic parts may be substituted for these if feasibility tests had indicated that metal parts are not needed. Hinging the blades to the hinge plates forms two subassemblies. Test models of this concept indicated that no difficulty would be encountered in assembling this concept.

Concept A is the most complicated of the three concepts. It requires numerous parts and these parts are not interchangeable. Many metal parts are required to withstand the loads induced by the parachute opening snatch forces. The parts are relatively complex to machine. The release mechanism, marker container, and the outer container form three subassemblies of the munition.

Munition Cost

In evaluating the relative costs of the three concepts consideration was given to tooling, material and labor costs, detail complexity, equipment requirements, and production support effort in terms of quantity production.

Concept C was rated as the most economical to produce in large quantities. It is simple in design, utilizes relatively low-cost plastic parts, and tooling costs would be limited primarily for molding dies used to form the plastic parts. Assembly equipment and production support effort should be low compared to Concepts A and B.

Concept B is similar to Concept C with the exception of the added complexity of the blade hinges and end plates. The munition cost of concept B should be slightly higher than Concept C.

Concept A is considered to be the most expensive of the three concepts, based on the complexity, tooling, material and labor costs.

Development Cost

Development cost includes costs incurred in all phases of work in the development of the munition up to and through aircraft drop testing and final design submittal. The cost would be related to time required for detail design, fabrication for testing, rework, and fabrication of quantities for aircraft drop testing.

A comparison was made of the design detail of each concept, estimates of the fabrication time required, and possible rework time of munition quantities for aircraft drop testing. The results indicate that Concept A would have the lowest development cost followed by Concept C and Concept B respectively. The biggest cost factor is the tooling required to fabricate the plastic parts for Concepts B and C, which for small quantities, places the two concepts at a price disadvantage.

<u>Operation</u>

Reliability

The relative design reliability of the three concepts was evaluated as a critical criterion in the selection of a specific concept for detail design and development. The reliability evaluation was directed toward the determination of the relative degree to which each concept could be made fail safe. In all cases personnel safety was given uppermost consideration.

The features given consideration were the sequence of operation required to release the markers after munition ejection from the dispenser, and redundancy incorporated into the design to provide a secondary means for marker release. Of prime importance was the nonhazardous condition of the munition when the redundant release system is actuated.

Concept A relies upon the parachute snatch force to activate a release mechanism to discharge the payload. In the event the parachute fails to open, a bore rider release mechanism provides a secondary means to discharge the payload. However, the ground troops will still be vulnerable to the partially opened parachute and the empty container. To eliminate this hazard the use of pyrotechnics to disintegrate the container was considered.

Concept B depends upon a wind tab or locking end caps to release the autorotating vanes. A pyrotechnic bore rider release device initiates a mild expulsion charge after a slight delay to release the autorotating vanes, as a secondary means to release the payload. Once the vanes are activated they will slowly descend and eliminate the problem of an empty container as in Concept A.

Concept C utilized a drag place or a small drag device to release the end plates holding the staves together which in turn release the staves. The end plates and staves rotate and glide earthward. As in Concept B, the secondary release device utilizes a bore rider pyrotechnic system to blow the end plates off to free the staves.

Concept B and C were given almost equal ratings, 8.5 and 8.3 respectively, while Concept A was rated 8.0.

Maintainability

Maintainability is a feature necessary to ensure that the munition is available for immediate use under field environment.

In this evaluation all concepts were almost equally rated on the basis that the munition upon final assembly would be loaded into a SUU-13/A canister and pinned in place. Thus the munition becomes a sealed unit and should be available for use at any time.

Realism

Realism is a feature to be judged from the viewpoint of troop reaction to the effectiveness of the exercise munition.

In this evaluation consideration was given to the capability of the munition to saturate the target area with markers, assuming marker dispersion would be the same in each case; in other words, the number of marker impacts per unit area for a given area coverage.

Concepts B and C were given the highest rating due to their greater marker carrying capacity. The parachute required for Concept A reduces its payload considerably in comparison with the other concepts, resulting with a low rating.

AERODYNAMIC ANALYSIS

The performance of the Retarded Exercise Munitions System is dependent upon the aerodynamic forces on the munition components and markers from aircraft delivery to ground impact. The sequence of operation of the munition involves the following:

(1) Safe separation from aircraft

(2) Munition dynamics which includes munition ballistics after ejection until munition opening and terminal effects of the munition parts.

(3) Marker trajectory and impact velocity.

Aerodynamic analysis to study safe separation from aircraft and munition dynamics were performed during Phase I on candidate munition concepts based on munition weights of 6 and 8 pounds. The marker trajectory and impact velocity analyses were performed during Phase II prior to the aircraft ejection test. The safe separation from aircraft analysis was repeated for a munition weight of 3.75 pounds prior to the aircraft ejection test. The aerodynamic analysis performed during Phase I is presented in the following paragraphs.

Safe Separation

The safe separation of the ejected cylindrical munition from a SUU-13/A type dispenser mounted on a high performance aircraft was examined. The study was primarily concerned with the effects of varying munition weight due to different types of packaged markers, and a range of ejection velocities due to marker weight differences as well as various ejection cartridges which can be used with the SUU-13/A type dispenser. Only the high aircraft release speed (550 knots) at sea level conditions was examined as the most critical separation case encountered during the ejection phase.

Figures II-7 and II-8 compare the separation distance between aircraft and ejected cylindrical munition for two extreme munition attitude conditions, nontumbling cylinder and a cylinder trimmed at a maximum lift-to-drag ratio. Examination of the two candidate cases reveal the following:

(1) At a selected time after ejection and a fixed munition weight and ejection velocity, distance is less for the cylindrical munition trimmed at maximum L/D; however, these distance differentials between candidate cases are small.

(2) At a selected time after ejection for a fixed munition attitude and ejection velocity, the heavier cylindrical munition will experience the larger separation distances from the aircraft. Once again, this difference in separation distance is small for 2-pound munition weight differences.

(3) At a selected time after ejection, for the fixed munition attitude and weight, the separation distance is larger for the larger ejection velocities. This separation distance is significant.

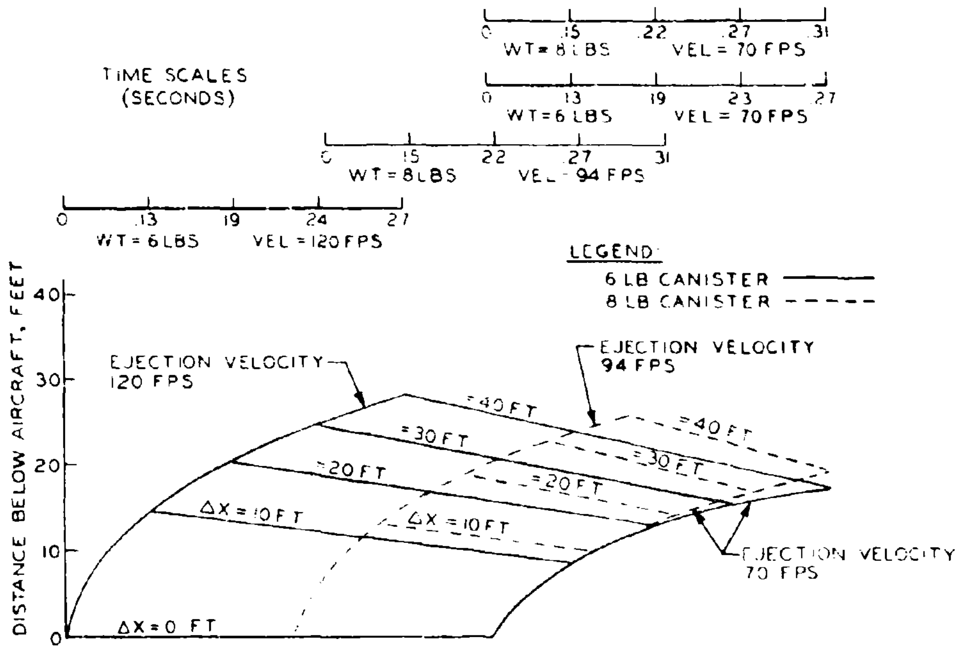


Figure II-7. Safe Separation Distance for a Non-Tumbling Munition

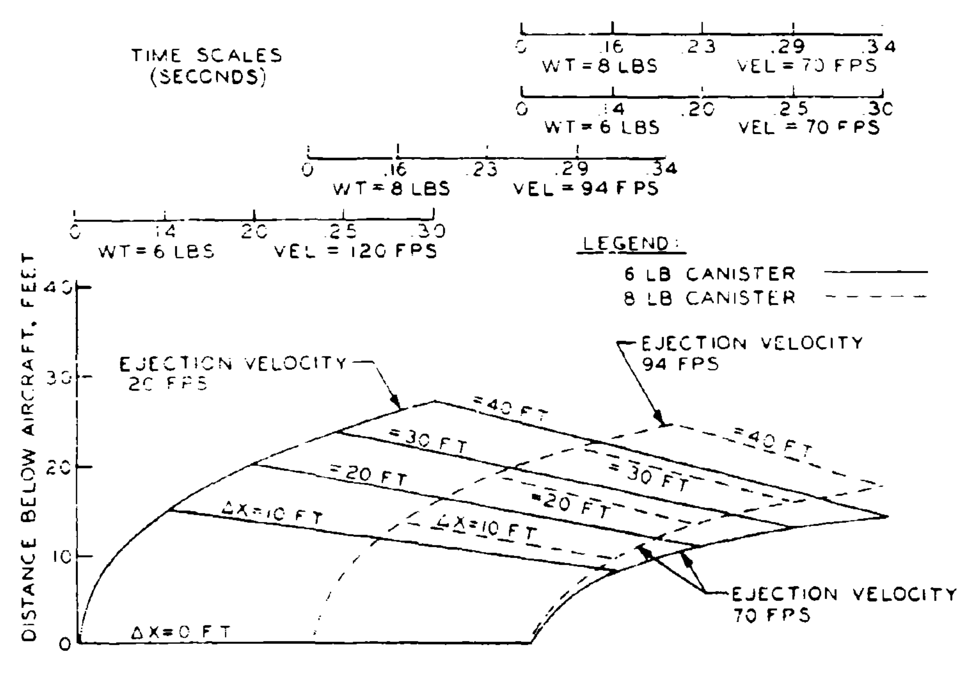


Figure II-8. Safe Separation Distance for a Munition Trimmed at Max. L/D

Based upon item (1) through (3), it can be concluded that a munition weighing 6 or 8 pounds ejected from the SUU-13/A type dispenser will safely separate from the aircraft for ejection velocities as low as 70 fps, regardless of munition attitude during the ejection cycle.

Figure II-9 pertains to the safe separation characteristics of a cylindrical munition with a 2.6-foot diameter parachute attached to the munition and deploying immediately after the munition clears the dispenser can. Items (2) and (3) in the past paragraphs also apply for the parachute configuration. In addition, it should be observed at a selected time after ejection, larger aft separation distance (AX) occurs for the parachute system as compared to the case which did not employ an aerodynamic decelerator. However, the vertical separation distances in the case of the parachute are less when compared to its candidate system. Thus, in the case of the parachute munition system, the cylindrical munition will safely separate from the aircraft for all weights examined and ejection velocities equal to and above 94 fps. Below 94 fps, for six- and eight-pound munitions, safe separation appears marginal, but this is remedied by delaying the parachute opening by 0.10 second after the munition clears the dispenser.

Munition Dynamics

The munition dynamics pertain to the munition ballistics within the parameter after ejection from the dispenser until munition opening, as well as terminal

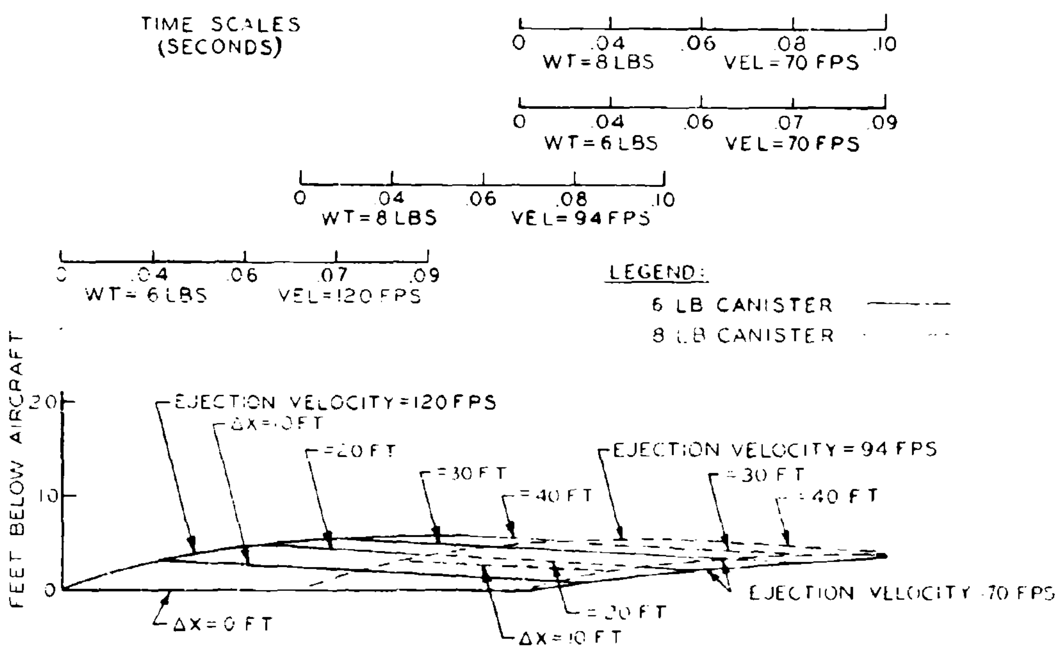


Figure II-9. Safe Separation Distance f r a Parachute Munition

effects of the munition parts after dispensing the markers. The former effect was discussed previously. The latter effect will be discussed in this section and will primarily deal with the parachute retarded concept and barrel stave concept.

Parachute Munition

The parachute munition concept affords low impact energy levels. But if chute failure should occur, munition case impact energies will exceed non-hazardous levels.

Figure II-10 represents the impact energy versus opening altitude of the empty munition case for both the high and low aircraft velocity releases.

The munition ballistic parameters at the time of submunition dissemination are listed in table II-3.

Table II-3 data was obtained from a 3-degree-of-freedom trajectory program using the ejection test data for the 8 pound munition ejected from a SUU-13/A type canister (standard cartridge). Figure II-10 indicates that the munition should not be opened at altitudes less than 100 feet above the terrain for the high-speed release and low-speed case for impact energy levels equal to or less than 15.0 foot-pounds (reference 1). The 100-foot level release will allow for a safe separation distance between aircraft and munition, sufficient altitude for the munition case to have a safe impact energy level, and dispersed altitude for the submunition markers. The above conclusion is based upon opening the

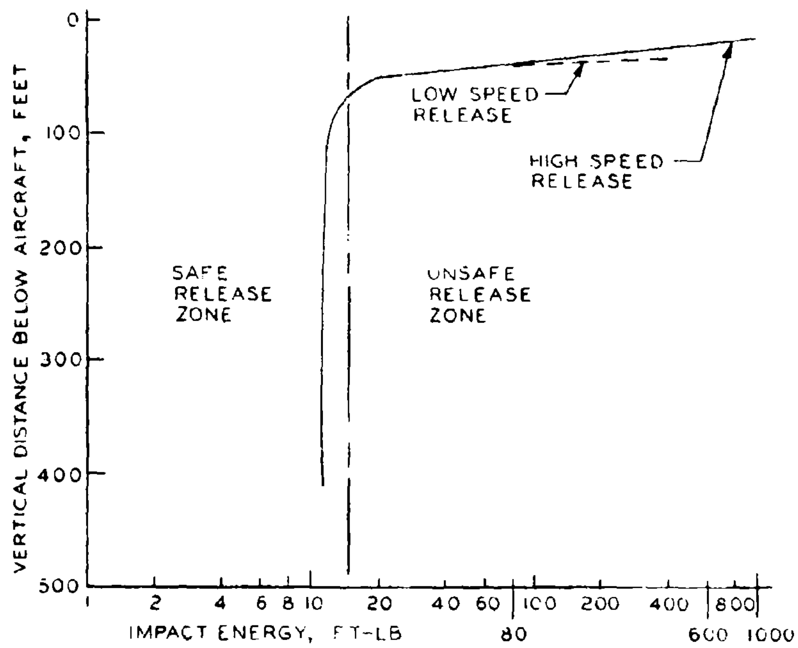


Figure II-10. Altitude Versus Impact Energy for a Parachute Munition System

TABLE II-3. PARACHUTE MUNITION BALLISTIC PARAMETERS AT SUBMUNITION DISSEMINATION

Time (Sec)	Opening Altitude (feet)	Slight Pull Angie (degrees)	Velocity (fps)	Type Aircraft Release	Empty Canister Weight (pounds)
0.30	487	-10.2	180	High Speed	2
0.30	470	-31.0	98.2	Low Speed	2

parachute 0.1 second after the munition leaves the aircraft dispenser. To operate the system at opening altitudes less than 100 feet above the terrain and still maintain a safe impact energy relationship (equal to or less than 15.0 foot-pounds), a larger size parachute must be used to decelerate the empty munition canister even more rapidly than the present case. An increase in the parachute size has its inherent problems in that the package volume increases, and loads on the munition at chute opening increase rapidly with an increase in canopy diameter requiring a heavier structure to withstand the increased stresses.

Stave Munition

At opening, the stave munition splits into two distinct configurations which consist of two plastic cylindrical disks 4.62 inches in diameter, attached by a common cord, and 16 flat plates of aspect ratio 10 and a weight of 0.065 pound. The disks, because of their low ballistic coefficient, will not present a hazard to ground personnel. The staves, however, require analysis to ensure that a hazard to ground personnel is not encountered.

After munition opening, there are two extreme flight modes. In one mode, the stave achieves an angular velocity about its longitudinal axis of symmetry and induces a Magnus lift. If the Magnus lift vector opposes gravity, the flight path velocity decreases. Figure II-11 (which came from reference 2) presents angular rate versus time and drag coefficient versus velocity along the flight path for a flat plate of aspect ratio 1.1. Hence, impact energies as low as 4.95 foot-pounds are not unreasonable. The stave munition concept has a larger aspect ratio than 1.1, and reference 2 indicates flight path velocity was reduced for an increase in aspect ratio for the same weight. The impact energy level should be about the same as previously listed if the flat plate autorotates, is stabilized in the proper plane, and has sufficient time to attain large enough Magnus lift values.

In the other extreme flight mode, the stave achieves minimum drag (the flow velocity parallel to the stave longitudinal axis of symmetry). Table II-4 presents the aeroballistic data at munition opening which was inserted in a 3-degree-of-freedom program.

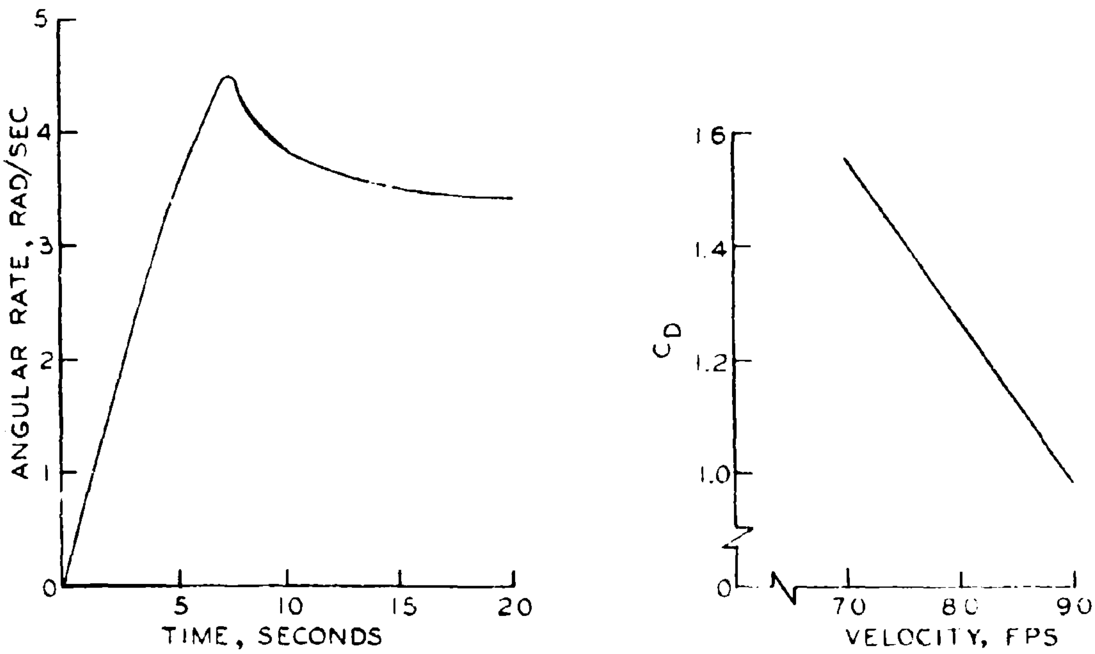


Figure II-11. Aerodynamic Characteristics for a Flat Plate of Aspect Ratio 1.1

TABLE II-4. AEROBALLISTIC DATA AT MUNITION OPENING FOR THE STAVE MUNITION CONCEPT

Time (sec)	Opening Altitude (feet)	Flight Path Angle (degrees)	Velocity (fps)	Type Aircraft Release	Stave Weight (pounds)
.20	474	-8.88	768.3	High Speed	.065
.20	470	-27.7	264.7	Low Speed	.065

Figure II-12 presents the terminal results of the stave in the minimum drag orientation for various opening altitudes as a function of impact energy. The safe opening altitude for the high and low speed release for the stave concept is 160 feet. This munition opening altitude will not violate the minimum energy requirements of 15.0 foot-pounds. It can be concluded that the stave concept will prove feasible as a potential means of disseminating the submunition markers without jeopardizing ground troop personnel in the immediate area.

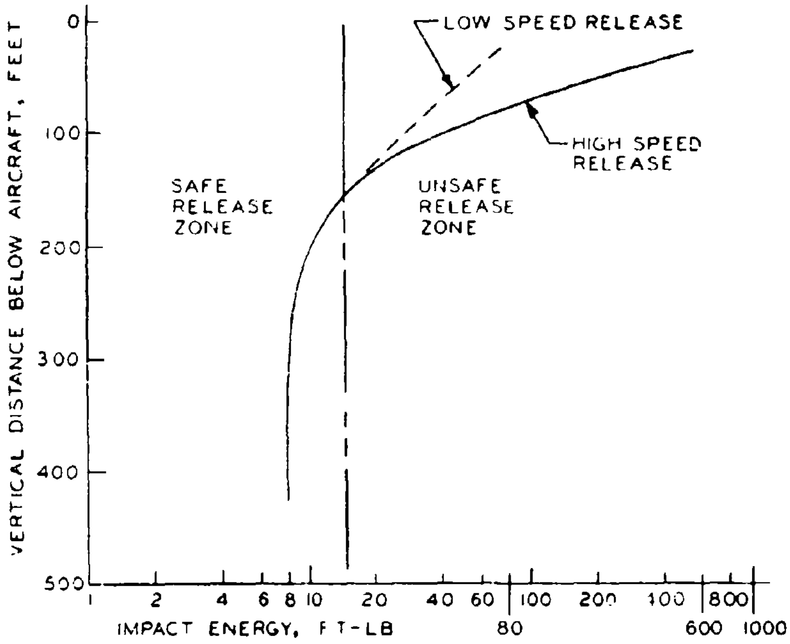


Figure II-12. Dynamic Characteristics for a Stave Munition System

The effects of using a munition which is lighter in weight than 8 pounds would tend to relax the minimum opening altitudes due to the decrease in ballistic coefficient, causing the munition to decelerate faster over shorter distances.

It would be borne out that the best orientation the stave can assume for minimum impact energy is that of an autorotating flat plate; however, it is recognized that it will not always achieve this flight mode. If the autorotating flight mode is not achieved by the stave, than the other flight mode will also satisfy the minimum requirements, provided the stave is given sufficient time to deplete its velocity to a value which allows the minimum energy requirements to be satisfied.

Drag Plate Retardation

The effectiveness of the fiberglass drag plate as a retardation device was investigated. The data used in the computer program was based on the plastic pusher plate being retarded by the fiberglass drag plate interconnected by a shroud line. The objective was to establish the terminal velocity and deceleration rate of the pusher plate assembly, with and without the drag device. The deceleration and velocity curves are shown in figures II-13, II-14, and II-15. The velocity is the resultant velocity of the downward ejection velocity and aircraft velocity. The pusher plate with the drag device has a terminal velocity of 40 fps and the impact energy is 14.9 foot-pounds, resulting with a unit impact energy of 8.43 foot-pounds per square inch, using the flat surface of the rim of the pusher plate as the impacting area.

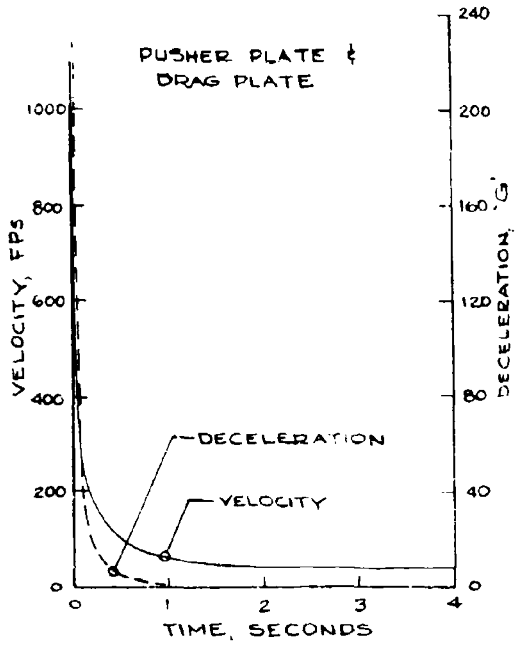


Figure II-13. Pusher Plate and Drag Plate Deceleration

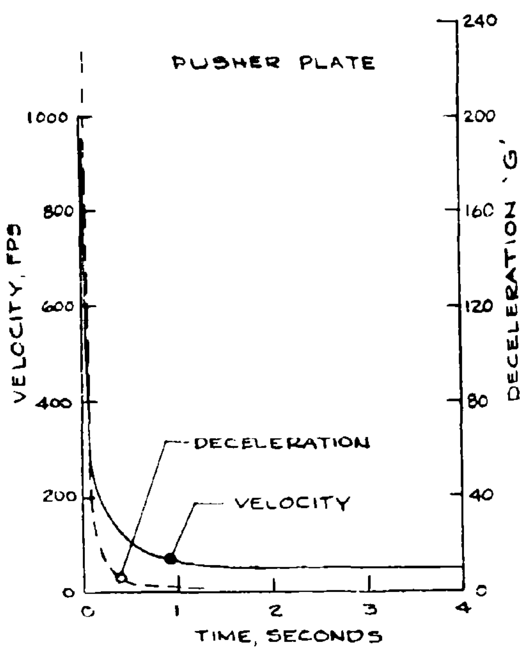


Figure II-14. Pusher Plate Deceleration

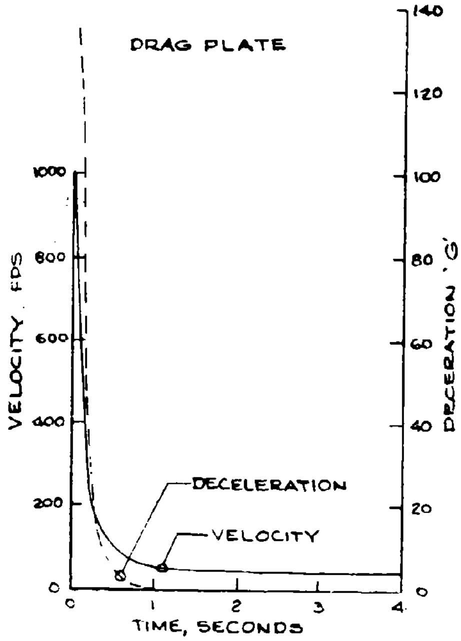


Figure II-15. Drag Plate Deceleration

APPENDIX III

STRESS ANALYSIS

To assure safe separation of the munition during ejection, the munition structure must withstand the induced stresses resulting from the ejection, hydrostatic and aerodynamic forces. Stress analysis of the munition structure was coordinated with the design effort to ensure munition structural integrity. The analysis was performed on a thin-walled cylindrical container and a barrel stave container.

AERODYNAMIC FORCE

The aerodynamic forces acting on the munition is expected to be greatest at exit from the SUU-13/A dispenser upon ejection at an aircraft velocity of 550 knots. The force was computed to be 310 pounds. Assuming the force is acting at the center of the outer case, a bending moment of 473 inch-pounds is created. The munition is considered to be a simple beam with the force acting at the center. The graph (figure III-1) shows the wall thickness required for yield stresses of plastic materials ranging from 2000 to 8000 psi.

EJECTION FORCE

The wall thickness required to withstand compressive stresses induced by the downward ejection force on a thin-wall plastic cylinder was computed. The downward ejection pressure was estimated to be approximately 260 psi which creates a downward force of 4370 pounds. The wall thickness required for stress values varying from 2,000 to 8,000 psi at 2000 psi increments were computed and plotted (figure III-2).

A comparison of the results shows that a greater wall thickness is required to withstand the downward ejection force. Column loading under the downward ejection force was not taken into consideration for the thin-wall cylinder since the unsupported length is less than eight times the least transverse dimension.

The critical stress for an eight-stave canister was computed to be 148.0 psi using Euler's formula for a column with both ends rounded.

$$S_c = \frac{{}^2E}{(L/r)^2}$$

where

S_c = critical stress

L/r = slenderness ratio of column

E = modulus of elasticity

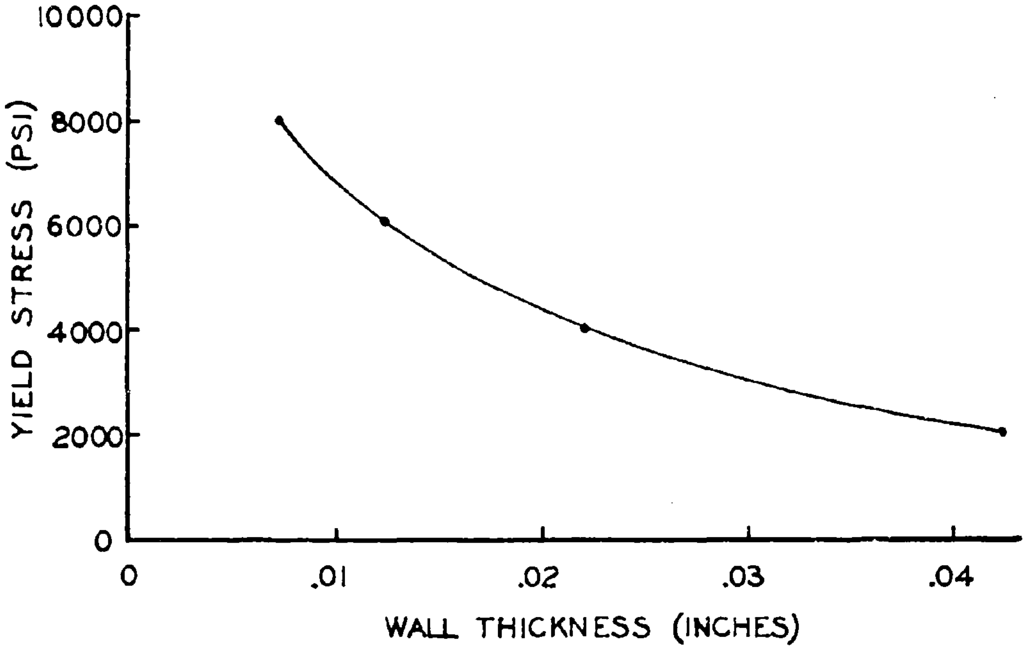


Figure III-1. Wall Thickness to Withstand Aerodynamic Force

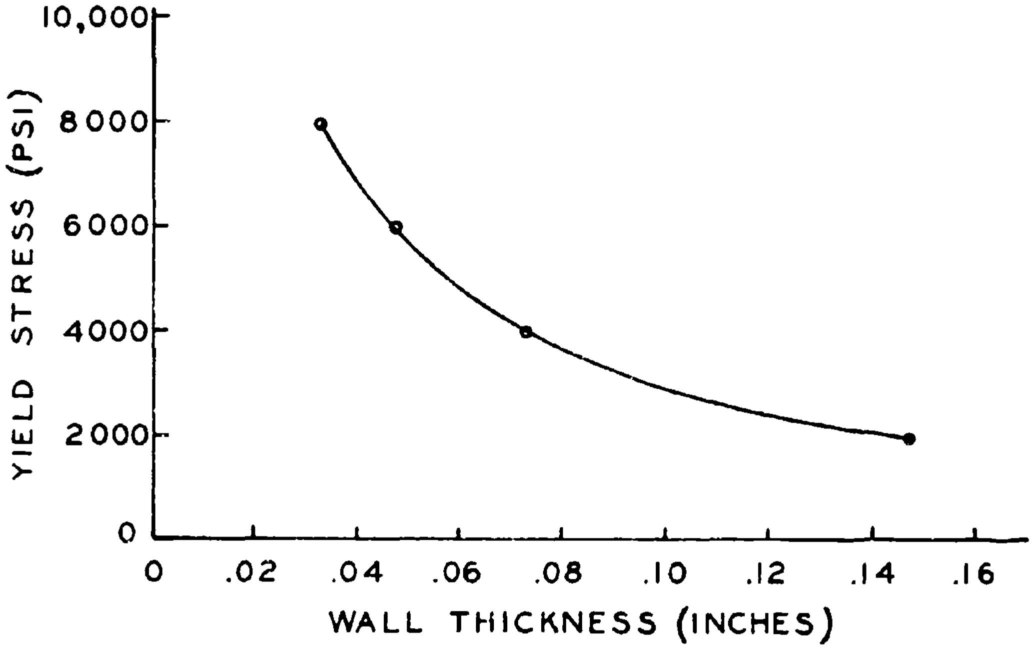


Figure III-2. Wall Thickness to Withstand Downward Ejection Force

HYDROSTATIC FORCE

The induced stresses resulting from the hydrostatic pressure was determined by computing the pressure resulting from the g force at ejection. The hydrostatic pressure of the canister without the separator disk is 113.5 psi and is reduced to 17.9 psi with the separator disk.

The bending stress induced on the canister staves without the separators is 292,000 psi. For a canister with the separator the bending stress is 25,000 psi. For a cylindrical container the hoop stress is 307 psi. The high bending stress produced by the hydrostatic pressure indicates that filling the barrel stave canister with fluid in a frangible bag is not practical.

APPENDIX IV

TACTICAL FIGHTER DISPENSER MUNITION

A "paper study" for a retarded exercise munition system for the tactical fighter dispenser (TFD) was performed after sufficient technical data was accumulated to establish design feasibility of retarded munitions concepts for the SUU-13/A dispenser.

Current available information and data of the TFD series including the TFDM, ATLM, and WAAPM were reviewed. The design, operation, and dispensing characteristics for those munitions presently developed for use with these dispensers were also investigated.

The initial studies were directed towards interchangeability of munitions between the TFD series and SUU-13/A dispensers. It was concluded that the munitions for each of the dispensers are not readily interchangeable. It was noted during the review of the TFD series that the Government is currently investigating a version of the TFD which incorporates an adapter for the TFD to utilize munitions designed for the SUU-13/A dispenser. The balance of the effort expended on the "paper" study was concentrated on generating various design concepts for use with the TFD and WAAPM dispenser. Discussion and sketches of various munitions concepts are presented in the following pages.

TFD MUNITION

The retarded exercise munitions designed for the TFD have the same overall dimensions as the TFDM manifolds (figures IV-1 and IV-2). This permits the exercise munitions to be loaded into the TFD bay with no modification to the existing hardware.

Four munition concepts for the TFD's are presented. These concepts are basically similar to the concepts evaluated for the SUU-13/A dispensers. The overall dimensions of these concepts are 3 by 3 by 14.25 inches and their weight varies from 4 to 6 pounds. Depending upon the concepts, the payload capacity varies from 900 to 1300 flechette-type markers.

The parachute retarded concept (figure IV-3) consists of a square, oblong marker container open on one end with the parachute attached to the closed end. The container is filled with the markers and sealed by a plastic front plate which is lightly pressed and bonded in place. The parachute and shrouds are packed into a thin plastic cover which fits over a shoulder at the closed end of the container. The weight of this munition is estimated to be 6 pounds fully loaded and 1 1/2 pounds empty.

In operation, the impinging air on the munition blows the parachute cover plate off and deploys the parachute. The opening snatch force of the parachute induces a retardation g force on the payload of sufficient magnitude to force the front plate off and disperse the markers. The impact energy of the empty container retarded by the parachute is approximately 15 foot-pounds. The payload capacity of this munition by comparison will be considerably lower than the other retarded munitions for the TFD.

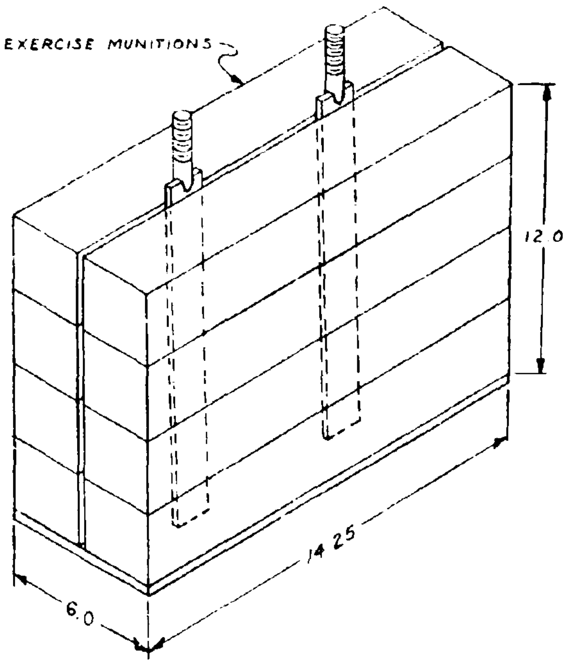


Figure IV-1. TFD Munition per Bay Loading

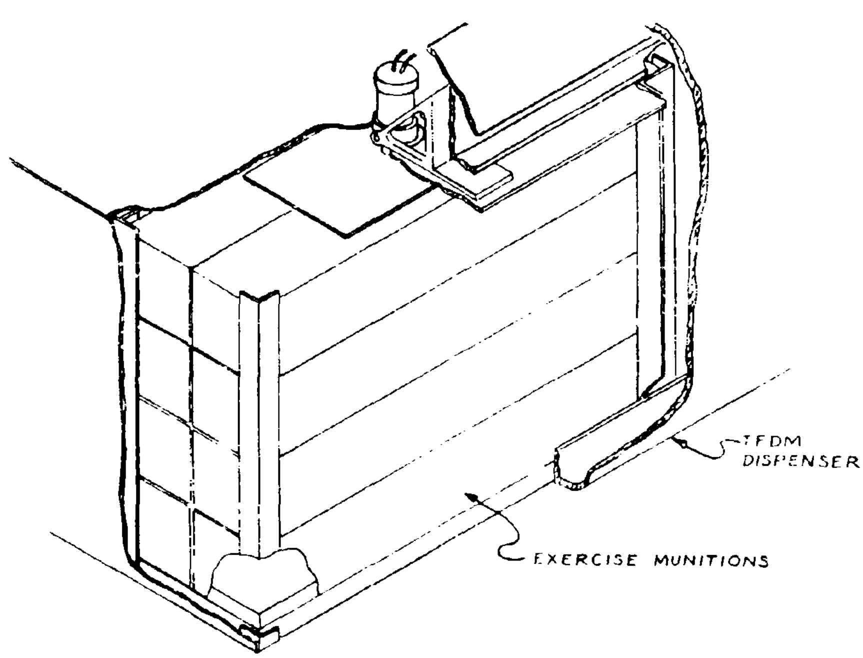


Figure IV-2. TFD Retarded Munition Packaging

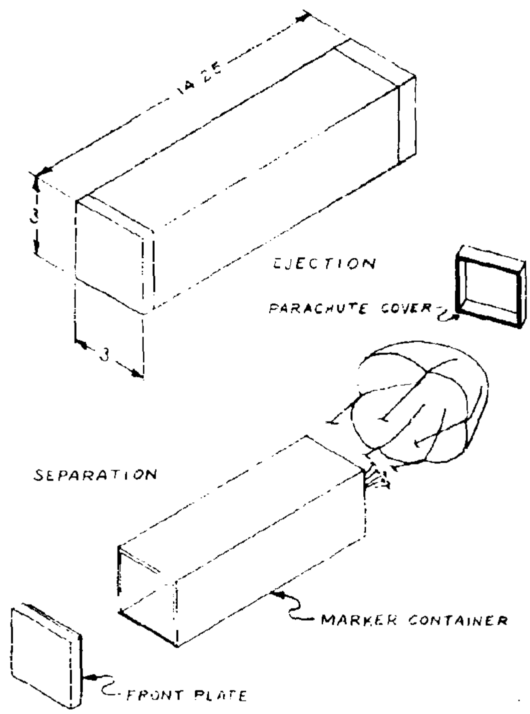


Figure IV-3. TFD Munition Parachute Retarded Concept

An autorotating vane concept (figure IV-4) is composed of the autorotating vanes attached to the rear cover plate, front plate, and frangible bag filled with the markers. The vanes in the closed position form the outer structure. The front plate is positioned by locating grooves at the tips of the vanes. The vanes and front plate are held together by a band wrapped around the outside of the container and locked together by a wind tab.

The sequence of operation after ejection begins with the wind tab being blown off by the impinging air. This releases the metal band and the vanes rotate around to the rear. The frangible bag is ruptured by the airstream and releases the markers. The hinges of the vanes are offset slightly to cause the vanes to autorotate. Aerodynamic analysis of a munition with autorotating vanes indicates that its rate of descent is slightly faster than a parachute retarded munition of the same weight, with the same canopy or vane diameter.

The rotating vanes and staves concept (figure IV-5) is composed of a drag sleeve assembly and a marker container assembly. The drag sleeve consists of a thin plastic sleeve which slides easily over the marker container. Four vanes are hinged at the aft end of the sleeve. The hinges are offset slightly to produce a slight pitch in the vanes when they are opened. The air striking the vanes in the open position will make it autorotate downwards. The marker container is formed with four flat plastic plates held together by caps which fit over the ends of the plastic plates. A square oblong frangible bag with the marker is packaged into the marker container assembly prior to final assembly.

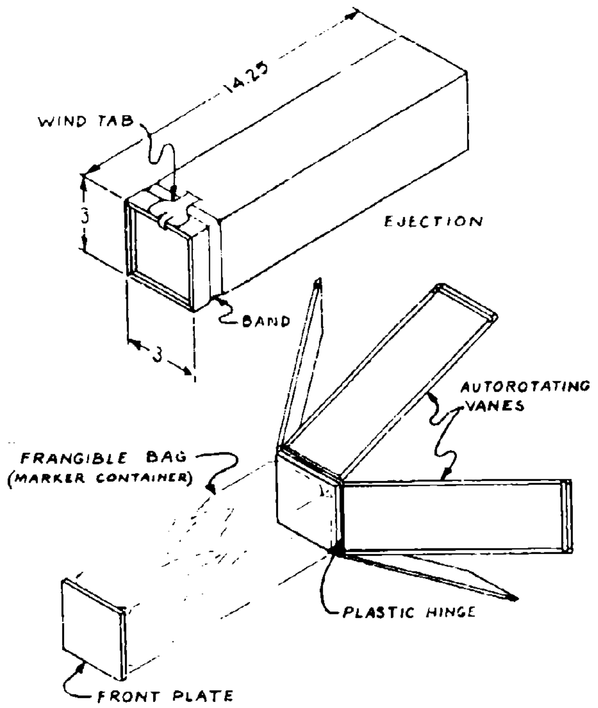


Figure IV-4. TFD Munition Autorotating Vane Concept

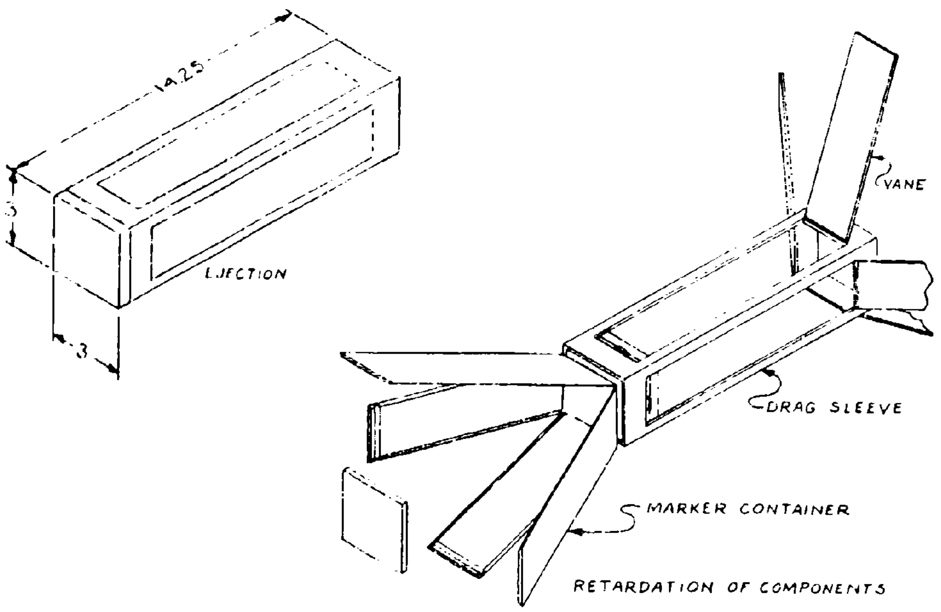


Figure IV-5. TFD Munition Autorotating Vane and Staves Concept

When this munition is ejected from the dispenser, the spring-loaded vanes begin to open. The air striking the vane rotates the vanes back, creating a drag force which pulls the drag sleeve to the rear of the marker container. The drag sleeve, impacting the rear cap of the marker container, pulls the cap off and releases the four plastic plates. The aerodynamic force causes the plates to fly apart, simultaneously rupturing the frangible bag to release the markers. The four plates and end caps become Magnus lift autorotating bodies and glide to earth while the drag sleeve with its vanes autorotates earthwards.

The stave concept (figures IV-6 and IV-7) is similar to the barrel stave concept recommended for the SUU-13/A dispenser. The components are the four staves (flat sideplates), end cap, forward cap with an integral secondary release system, a band, and a wind tab. When this munition is assembled, the four side plates are placed in the end cap and held together to form a marker container. A frangible bag filled with markers is packaged into the marker container. The forward plate is placed at the front and the entire assembly is held together by a band at the front of the container. The ends of the bands are held together by the wind tab.

The opening sequence of this munition begins as soon as the munition is ejected from the dispenser. The air impacting the wind tab at high velocity flips the tab off releasing the band around the staves. The staves blow apart as the band is released, and simultaneously the frangible bag breaks open and disperses the markers. In the event the wind tab fails to release the band, the secondary

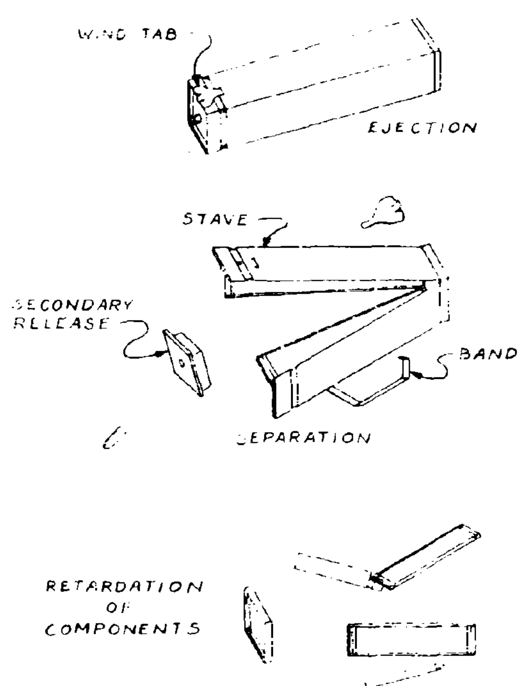


Figure IV-6. Operating Sequence of TFD Munition Stave Concept

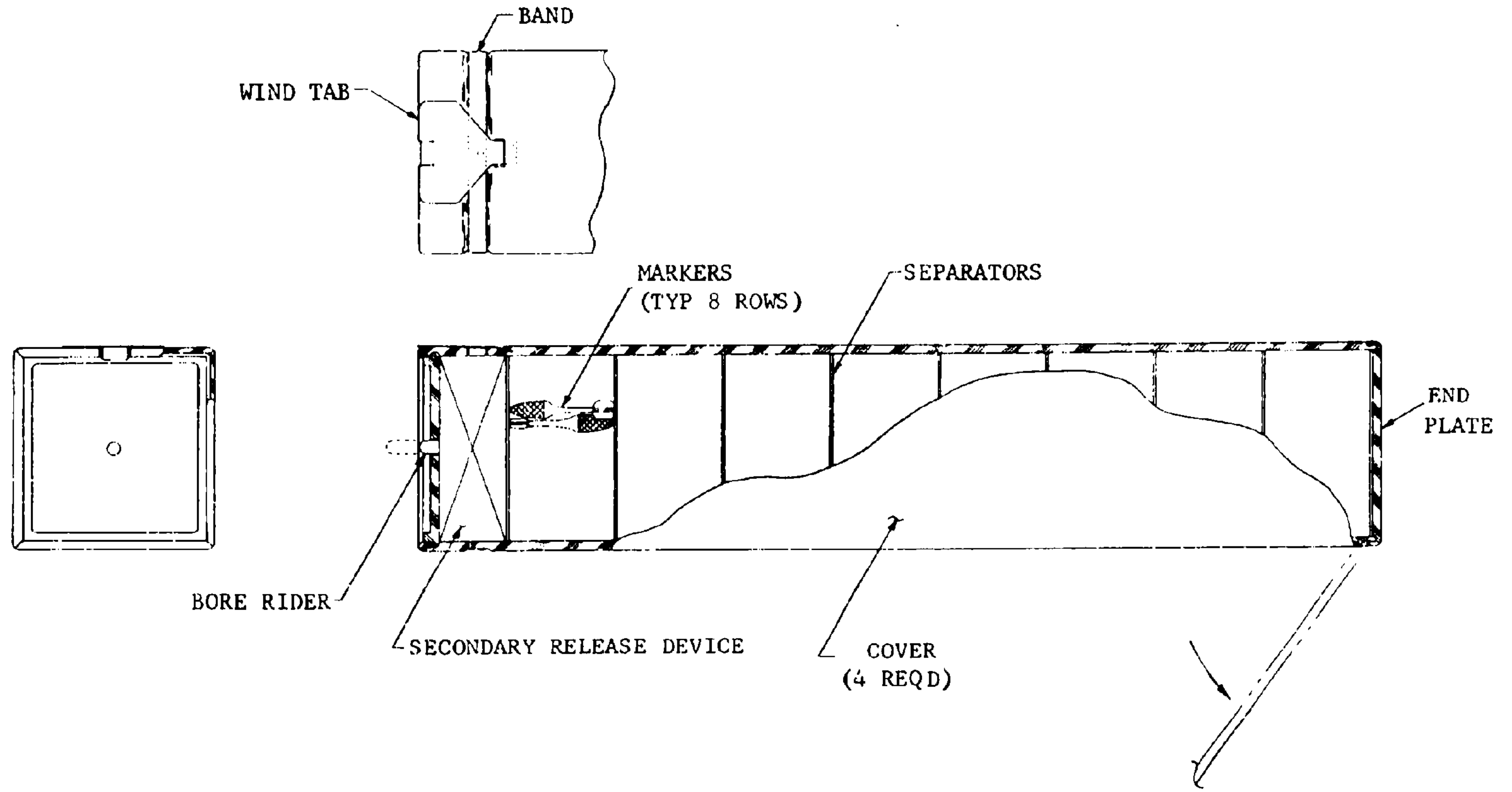


Figure IV-7. Preliminary Design of Stave Concept

release system actuates a mild expulsion charge which forces the end caps off and initiates dissemination of the markers.

WAAPM DISPENSER MUNITION

It was noted in reviewing the available information of the WAAPM dispensers that the overall dimensions of the munitions for the WAAPM dispenser approximate the overall dimensions of the SUU-13/A canister. The basic munitions concepts discussed for the SUU-13/A dispenser may be applied to the WAAPM dispenser, namely, the parachute retarded concept, the autorotating vane concept, and the barrel stave concept. Other interesting munitions concepts conceived for use with the WAAPM dispenser are discussed in the following paragraphs. The overall dimensions of these concepts are 4.64 by 5.92 by 11.77 inches and the weights vary from 6 to 8 pounds. The payload varies from 800 to 1100 flechette markers.

The Magnus lift concept (figure IV-8) consists of two cover plates, the container structure assembly, a band and a wind tab. The cover plates are made from 1/2-inch rigid polyurethane foam plastic and are identical in size and shape. The container structure assembly consists of two plastic end plates and a plastic interconnecting plate. The markers are packed on both sides of the interconnecting plate and enclosed by the cover. The bank is wrapped around the whole assembly and the wind tab forms the interconnecting link to hold the ends of the bands together.

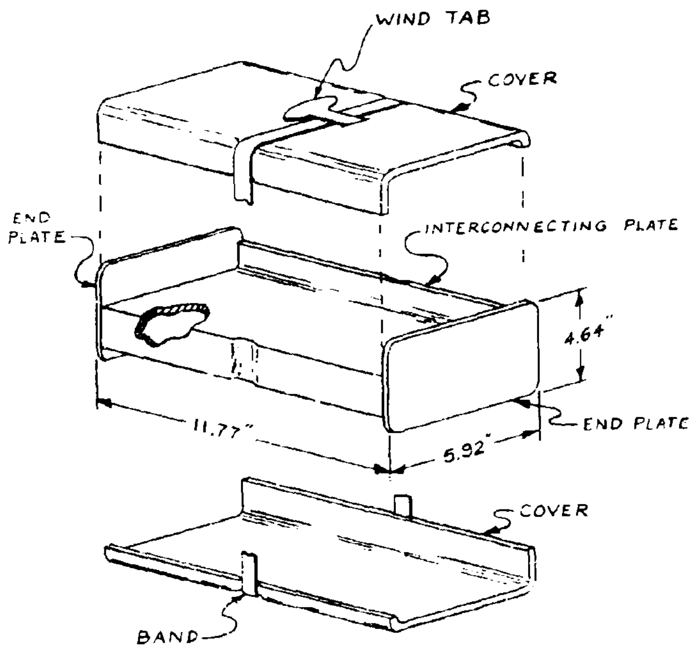


Figure IV-8. WAAPM Munition Magnus Lift Concept

When the munition is ejected from the dispenser, the air impinging on the wind tab flips the wind tab off and releases the band. As the band flies off, the covers are blown off and the markers are jettisoned. The configuration of the container structure assembly forms a Magnus lift body which rotates and glides earthwards.

The consumable case munition concept (figure IV-9) consists of a marker container assembly, a frangible bag filled with markers, and a bonded nitrocellulose filament-wound flame consumable outer case. The marker container assembly is composed of two half sheets and end plates formed from rigid polyurethane foam plastic. The munition is assembled by slipping the marker container assembly with one end open into the consumable outer case. The markers are packaged into the marker container and sealed in place by the top plate. The consumable case is crimped over and held in place by the pusher plate. The pusher plate has an ignition receptacle to eject the munition and to ignite the consumable case.

When the munition is ejected, a pyrotechnic train in the pusher plate ignites the consumable case and burns at a rapid rate until it is completely consumed. The marker container opens as the consumable case burns away and disperses the marker.

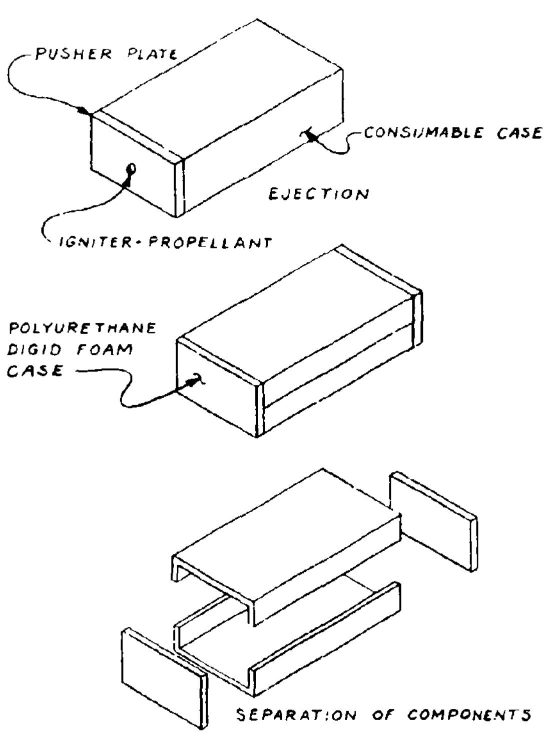


Figure IV-9. Consumable Case Munition Concept

APPENDIX V

RELIABILITY ANALYSIS

A reliability effort directed toward the elimination of potential failure modes which could result in conditions hazardous to ground personnel estimated that the barrel stave canister concept, utilizing aerodynamic forces alone for marker dispersal, could achieve functional reliabilities approximating unity.

Although reliability improvements is significant through the use of redundancy, aerodynamic separation is considered the prime design detailing requirement; the redundant mode is secondary. This concentration of effort results from a study of the relative effects on munition reliability of the primary and secondary modes of operation: munition reliability will increase at a higher rate for improvements in the primary mode than for equal increments of secondary mode improvements because of the estimated relative mode reliabilities.

The possibility of causing injury should be considered concurrent with the probability of ground-level impact of potentially injurious munitions. The very high munition reliability anticipated would appear to provide only a remote possibility of causing injury.

The redundancy calculations are as follows:

Primary canister separation mode: Aerodynamic; "R_a"

Secondary canister separation mode: Pyrotechnic; "R_p"

It is assumed that the modes are independent.

It is believed reasonable to assume reliability values in the order of $R_a \approx 0.995$ and $R_p \approx 0.985$ from previous experience extrapolated to the current program.

Redundant separation probability, R_s, (reliability) is calculated from:

$$R_s = 1 - (1 - R_a)\ (1 - R_p)$$

For $R_p = 0.985$

R_a	R_s
0.995	0.999925
0.996	0.999940
0.997	0.999955
0.998	0.999970
0.999	0.999985

For $R_a = 0.995$

R_p	R_s
0.985	0.999925
0.986	0.999930
0.987	0.999935
0.988	0.999940
0.989	0.999945
0.900	0.999950

It can be seen that a change in R_a has more influence on R_s than an equivalent change in R_p.

APPENDIX VI

AIRCRAFT EJECTION TEST

INTRODUCTION

For the markers to mark troops and ground targets, the retarded exercise munition delivered from an aircraft must disperse the markers over a predicted area for a given velocity and altitude with the desirable delivery and marking characteristics. The purpose of the aircraft ejection test was to (1) demonstrate that the retarded exercise munition would function in accordance to an operational sequence established as a design objective and the delivery method (2) munition components, markers, and marking material would be nonhazardous to ground personnel in the impact area.

PREPARATION

The information acquired during the preliminary tests was utilized to set up a computer program to determine marker trajectories, dispersions, impact velocities, and terminal velocity.

The target area and grid (figure VI-1) was established. The overall target size was 150 feet wide and 600 feet long. Impact angles of the flechette markers were determined by the trajectory computation. The individual targets were 2- by 24- by 24-inch rigid foam plastic blocks with and without canvas covering. The covered targets were used to simulate ground personnel in GI fatigue clothing and the uncovered targets were used to measure marker penetration which can be correlated to impact velocity. Safe separation of the downward ejected munition was computed and plotted for an aircraft velocity of 165 KTAS and 550 KTAS (figure VI-2). The time delay prior to munition separation and marker dispersion was estimated to be 0.2 second. A munition weight of 3.75 pounds was used in the calculation. Munition separation was computed to be 22 feet and 30 feet below the aircraft at velocities of 165 KTAS and 550 KTAS, respectively.

The flechette marker trajectories were computed and plotted for a maximum downward ejection velocity of 130 fps at aircraft velocities of 165 KTAS and 550 KTAS and at release altitude of 100 and 500 feet. For a velocity of 165 KTAS, the marker impact angle varies from 30 to 40 degrees when ejected from an altitude of 100 feet and is vertical when the altitude is 500 feet (figure VI-3). The impact angle varies from 20 to 40 degrees when ejected from an altitude of 100 feet and a velocity of 550 KTAS (figure VI-4). The impact angle is vertical when the altitude is 500 feet.

Half patterns of marker dispersion established by the computer program are shown in figures VI-5 through VI-8 with their respective release altitude, aircraft velocity, impact velocity and area. The marker dispersion changes from an elliptic pattern along the flight direction at the low release altitude to an elliptic pattern perpendicular to the flight path at the high release altitude. The area coverage decreases as the altitude is increased.

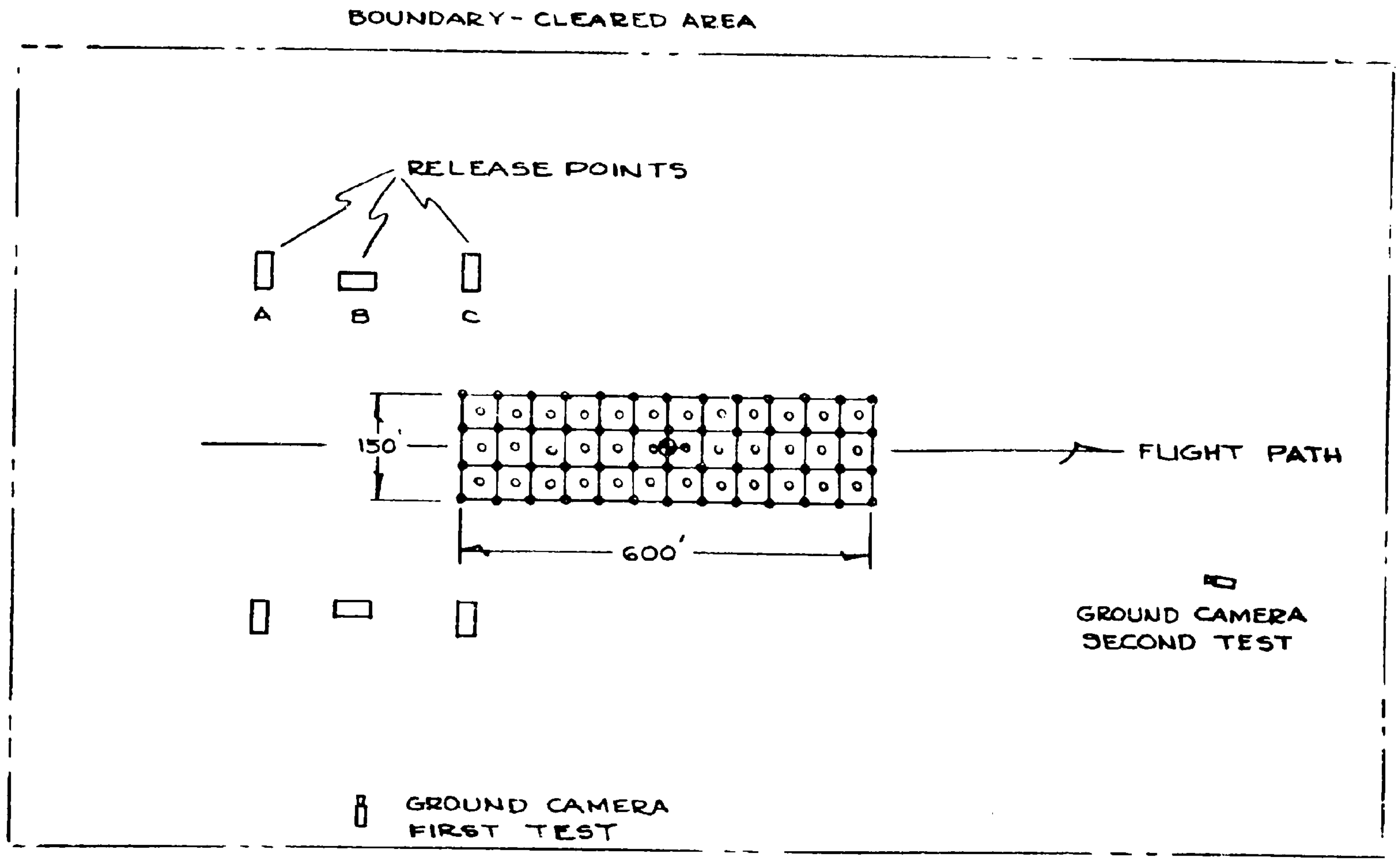


Figure VI-1. Target Area and Grid for Aircraft Ejection Test

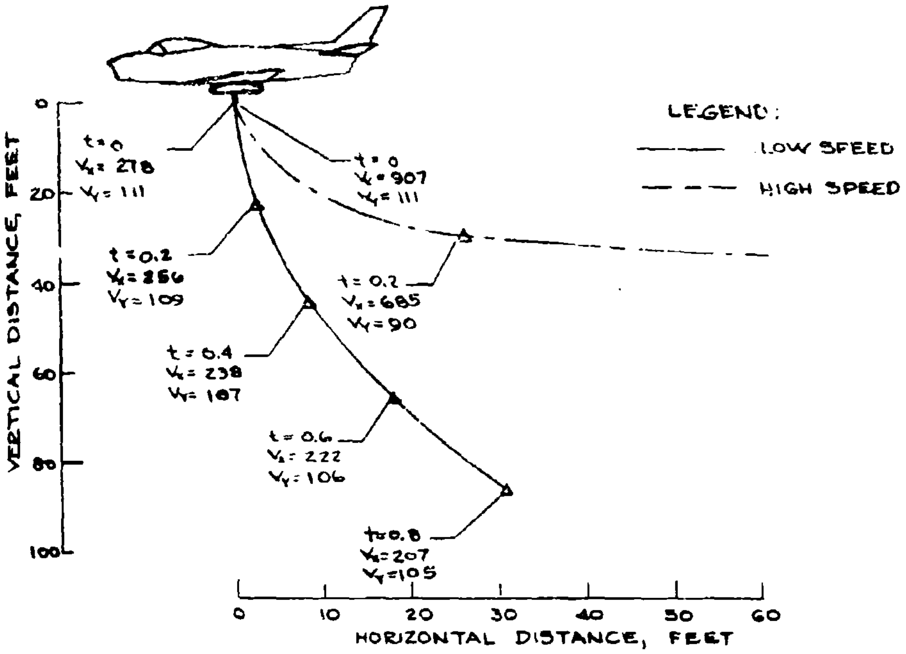


Figure VI-2. Safe Separation of Ejected Munition from Aircraft

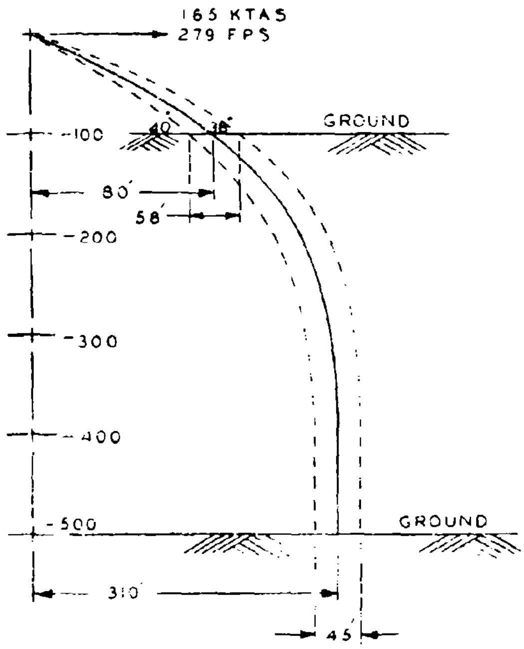


Figure VI-3. Marker Trajectory (165 KTAS)

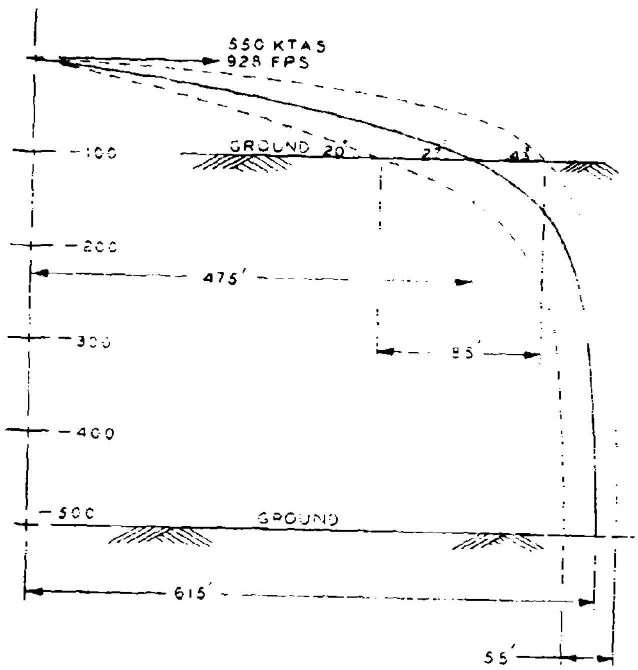


Figure VI-4. Marker Trajectory (550 KTAS)

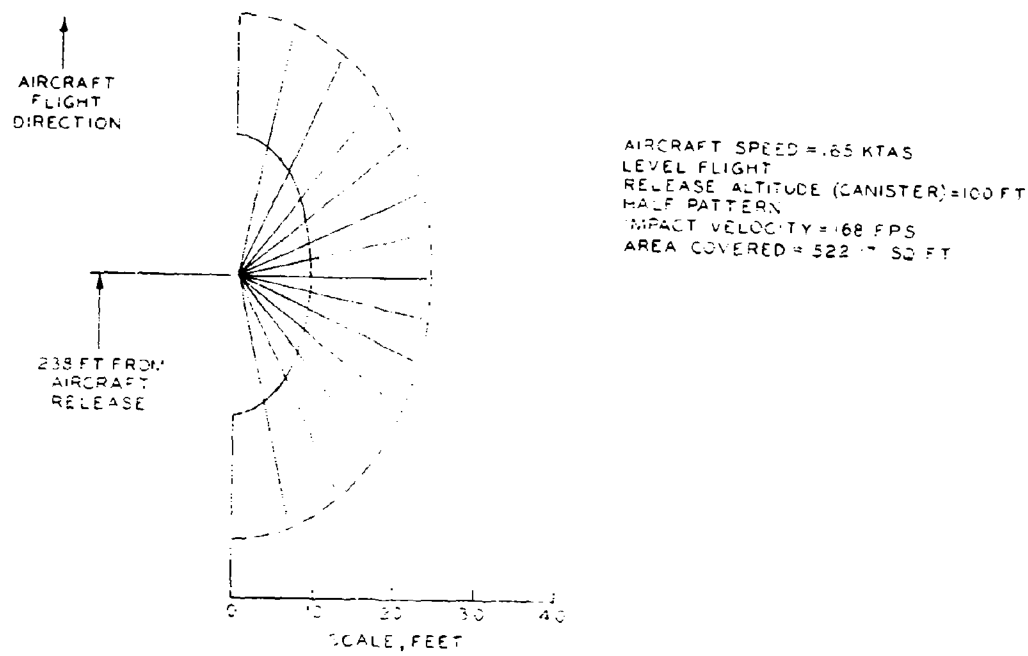


Figure VI-5. Marker Dispersion (165 KTAS at 100 feet)

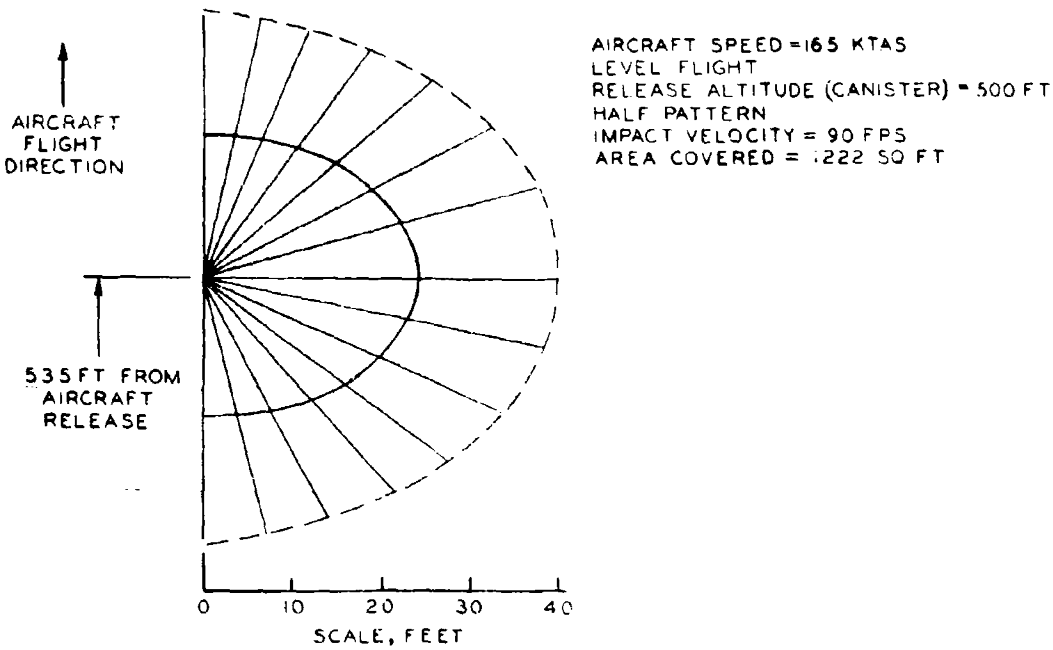


Figure VI-6. Marker Dispersion (165 KTAS at 500 feet)

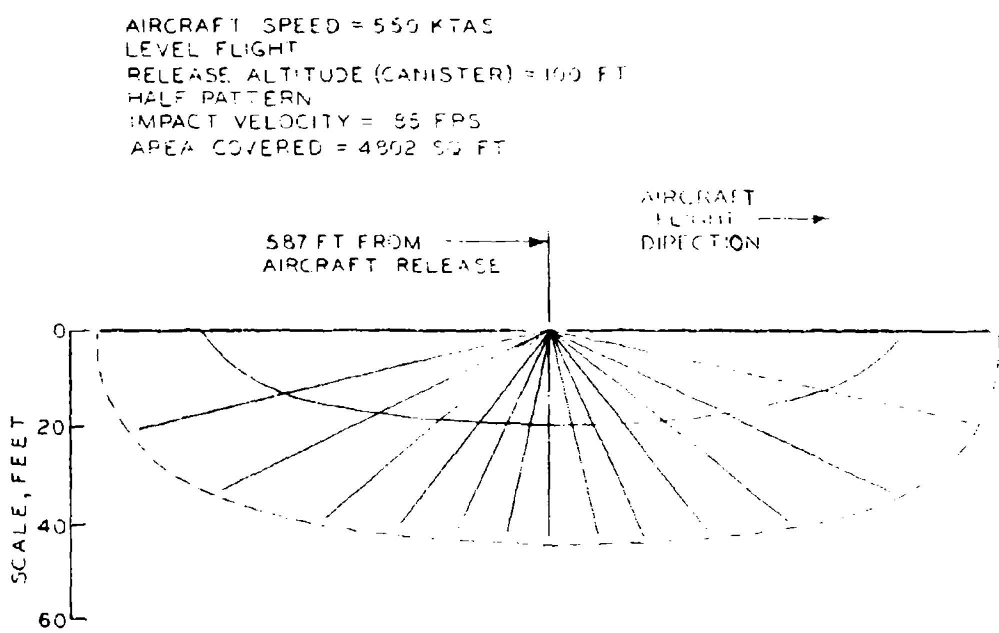


Figure VI-7. Marker Dispersion (550 KTAS at 100 feet)

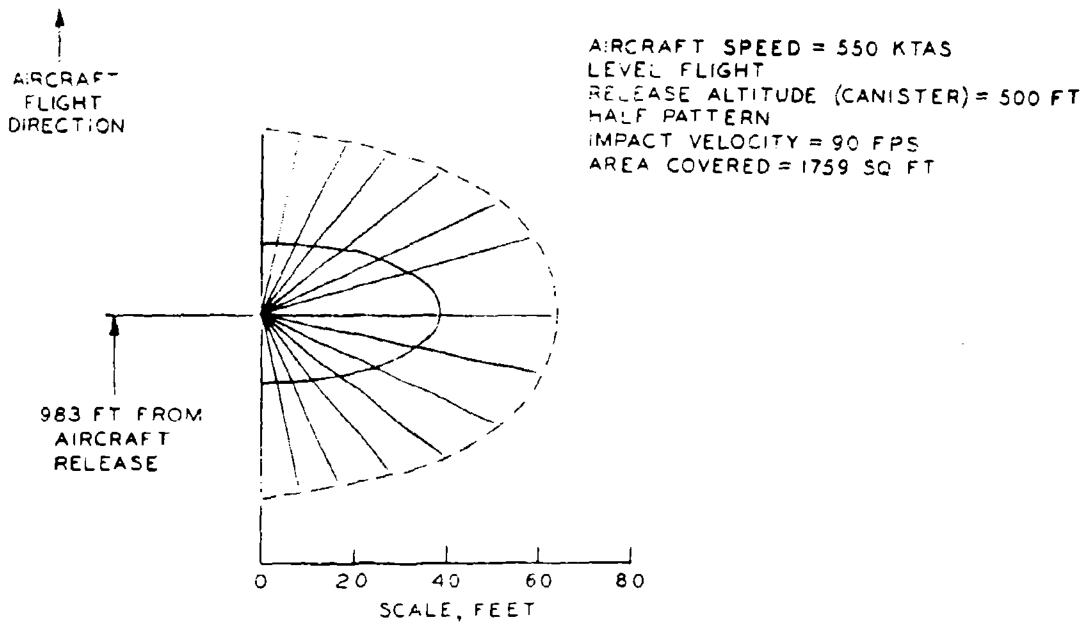


Figure VI-8. Marker Dispersion (550 KTAS at 500 feet)

The program established was to eject six munitions. The first two passes at 165 KTAS, the second two passes at 550 KTAS, and the third two passes were reserved for any contingency which might require a rerun of the previous passes. At each of the velocities, the first pass was made at 500 feet altitude followed by the second pass at 100 feet. Each munition was color coded to represent the color of the dye used in the markers for that munition. This was done to determine marker dispersion of each canister ejected, at the various velocities and altitudes, after the aircraft ejection tests were concluded.

(The reverse of this page is blank)

REFERENCES

1. Tactical Exercise Munitions, Wood-Ivey Systems Corporation, Technical Report AFATL-TR-67-77.

2. Dynamics & Aerodynamics of Bomblets - Conferences at Eglin AFB 26, 27, 28 September 1967.

3. Fluid Dynamic Drag. S.F. Hoerner. 1958 edition.

(The reverse of this page is blank)

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) NORTRONICS, A Division of Northrop Corporation 500 E. Orangethorpe Avenue Anaheim, California	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP
3. REPORT TITLE RETARDED EXERCISE MUNITION SYSTEM	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report - 1 August 1967 to 30 Nov. 1968	
5. AUTHOR(S) (First name, middle initial, last name) S. Maruko	
6. REPORT DATE November 1968	7a. TOTAL NO. OF PAGES 106 / 7b. NO. OF REFS
8a. CONTRACT OR GRANT NO. F08635-68-C-0003 b. PROJECT NO. 698U c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFATL-TR-68-138
Available in DDC	Air Force Armament Laboratory Air Force Systems Command Eglin Air Force Base, Florida

13. ABSTRACT

This program was to design, develop and test an operational downward ejected airstrike munition and marking material. These munitions are nonhazardous substitutes for munitions used in combat to be employed in joint field training exercise to produce air strike realism and provide tangible evidence of the air strike effects for evaluation. The munition designed, developed and tested was a munition configuration based on a barrel stave type canister employing a simple retardation device to actuate munition separation and to decelerate a rigid component to a nonhazardous impact velocity. The inherent design features of the retarded exercise munition provides sufficient flexibility to utilize a variety of marking submunition configurations. It was concluded that the retarded exercise munition is simple, economical and requires further development to be an operationally feasible nonhazardous exercise munition which provides realism and improved scoring accuracy.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Markers						
Marker dispersion						
Marker container						
Safe separation from delivery aircraft						
Impact velocity						
Unit impact energy						
Munition opening and separation						
Water soluble marking material						
Frangible materials and capsules						
Fluorescent pigments						
Autorotating vanes						
Parachute retardation						
Barrel stave canister						
SUU-13/A Dispenser						
TFDM dispenser						

AIR FORCE RESEARCH LABORATORY
MUNITIONS DIRECTORATE
AFRL/MNOC
203 W. Eglin Blvd, Bldg. 300
Eglin Air Force Base, Florida 32542-6843

FACSIMILE COVER SHEET

Date	15 Jun 2005	Time of day		# of pages including cover sheet:	6

TO:	Larry Downing DTIC-OCA	**FROM:**	Susan R. Miller
Phone:	*Comm#* 703-767-011 *DSN#* 427-0011	**Phone:**	*Comm#* 850-882-8235, ext 1231 *DSN#* 872-8235, 1231
Fax:	*Comm#* 703-767-9244 *DSN#* 427-9244	**Fax:**	*Comm#* 850-882-2207 *DSN#* 872-2207

REMARKS:

X	*Urgent*		*For your review*		*Reply ASAP*		*Please comment*	X	*Action*

ATTN: MR. DOWNING
Subject: Distribution Change to DTIC Record #AD854328
Report #AFATL-TR-68-138
Your email to me on June 10, 2005 9:54 AM

1. This report is marked "Cleared for open publication ADTC/OI, #1, 16 March 1978

2. Please insert enclosed corrected copies into the report in your records. Corrected copies being submitted for replacement of existing pages in your record are as follows:
   - Cover page
   - Page which would be "i" although not marked as such (page immediately following cover page)
   - Page "ii"
   - Page "iii"
   - DD Form 1473

2. If you have any questions, please contact me at DSN 872-8235, ext 1231, or by email at susan.miller@eglin.af.mil.

Thank you for your assistance.

Susan

Susan R. Miller
AFRL/MN STINFO Officer
Eglin AFB, FL 32542-6810
850-882-8235, ext. 1230 or 850-882-2731 (DSN 872)
email: susan.miller@eglin.af.mil